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Relating Predicted Fertilizer Response to Actual Growth and site Conditions

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RELATING PREDICTED FERTILIZER RESPONSE TO ACTUAL GROWTH AND SITE CONDITIONS

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ABSTRACT

Forty-five nitrogen fertilizer trials were established in six geographic regions: northern Idaho, central Idaho, Montana, northeast Washington, central Washington, and northeast Oregon. Two-year basal area growth was summarized for three treatments: control, 200 lb/ac N, and 400 lb/ac N. Nitrogen amendment significantly increased two-year basal area increment (BAI) in all six geographic regions. Fertilizer response varied substantially within and among geographic regions. Two-year growth was compared to predicted fertilizer response. No relationship existed between actual growth and predicted response. The Krauss (Weetman) foliar diagnostic technique was not a practical way to predict response to fertilization. BAI was modeled using site and stand attributes. Seventy-one percent of the variation in two-year diameter growth was accounted for in the model which included several site and stand factors and their interactions. Soil parent material and depth of volcanic ash were related to inherent rates of diameter growth and fertilizer growth response. The rates of growth of control plots according to soil parent material were till/fill > ash/loess > basalt > granite. Ash/loess, basalt, and granite soils all exhibited significant increases in growth due to fertilization while till/fill soils did not respond to fertilization. The two rates of fertilizer application resulted in little difference in growth gain at low levels of stocking. However, at high levels of stocking, 400 lb/ac N produced a greater response compared to 200 lb/ac N. This was particularly true on soils with deep layers of volcanic ash. Results demonstrate that it is feasible to build models of stand growth that include specific rates of nitrogen fertilization as an independent variable.

INTRODUCTION

Forty-one Douglas-fir nitrogen fertilizer trials were previously classified into three response categories: (1) no response; (2) strong response; and, (3) blocked, variable and weak response (USDA Forest Service Cooperative Agreement 22-C-INT-146). Prediction of nitrogen fertilizer response was based on the Krauss (1965) foliar diagnostic technique. The objective of the research reported herein was to relate predicted fertilizer response to actual basal area growth two years following urea application. A second objective was to model growth response following nitrogen fertilization using site and stand attributes. We initiated the research with three working hypotheses.

INITIAL ALTERNATIVE HYPOTHESES

1. Plots exhibiting higher needle weights and foliar nitrogen contents will grow (basal area growth) proportionally more two years after fertilization compared to plots exhibiting little or no change in needle weight and foliar nitrogen content. Simply stated, the Krauss foliar diagnostic technique could be used to predict fertilization response.

2. Site and stand factors like elevation, slope, aspect, habitat type, soil depth, bedrock type, stand age and stand density could be used to predict changes in needle weight due to fertilization.

3. Site and stand factors could be used to model basal area growth following nitrogen fertilization.

FIELD AND LABORATORY METHODS

Study Sites

Forty-five nitrogen fertilizer trials, termed installations, were established in 1981 by the Intermountain Forest Tree Nutrition Cooperative (IFTNC). Each installation consisted of six square or rectangular plots at least 0.1 acre in size; some plots were slightly larger so that a sufficient number of individual sample trees were included. The plots within an installation contained at least ten Douglas-fir sample trees and were as similar as possible to one another in terrain, vegetation, stocking, and tree size. In an effort to further reduce inter-plot variation the six plots were divided into two blocks of three plots each based on similarity in tree density and species composition. Three treatments were assigned to the plots at random. The treatments consisted of: (1) application of 200 lb/ac actual nitrogen; (2) application of 400 lb/ac actual nitrogen; and, (3) no nitrogen amendment. All fertilizer treatments were in the form of urea applied with a hand-held spreader in the late fall of 1981.

Installations were confined to second-growth, even-aged, managed stands of Douglas-fir. The installations, by design, were established in six different geographic regions:

Geographic Region	No. of Installations
northern Idaho	5
central Idaho	8
Montana	8
northeast Washington	9
central Washington	9
northeast Oregon	6

Installations occurred over a relatively broad range of environmental and stand conditions. Elevations ranged from 2,200' to 5,900', with a median of 3,500'. Soils formed in a variety of parent materials including volcanic ash, post-glacial fluvial and lacustrine deposits, glacial deposits, granite and basalt. Soils differed appreciably in their ages.

Average age of the various installations ranged from 32 to 100 years. Basal area per acre and average installation diameter (dbh) ranged from 48 sq ft/ac to 270 sq ft/ac and from 6.3" to 17.0" respectively.

Tree Measurements

The diameters of all sample trees were measured before treatment in the fall of 1981 and again after the 1983 growing season. Thus, the two-year growth response of the 45 installations was based on diameter (basal area) growth for the first two years following treatment.

Foliage samples were collected from two trees within each plot for a total of 12 per installation. Samples were collected one year following fertilization by climbing the trees. Shoots were collected from the third whorl from the top of the tree.

Site index was determined for each plot by destructively sampling two trees per plot. Trees were dropped in the plot buffer and tree height measured with a tape.

Site and Soil Sampling

Site characteristics were measured for each plot including: elevation, azimuth, and slope percent. Before fertilization in the fall of 1981, 10 soil samples were randomly collected from each plot. Samples were taken from the upper 10" of mineral soil and the 10 samples per plot composited in the field. Soils of 41 installations were described by excavating small pits during the summer of 1982.

Foliar and Soil Analysis

Foliage was oven-dried at 70 C for 24 hours and the needles were then separated from the twigs. Five replications of 100 needles were counted for each tree. Counted needles were then redried at 70 C for 24 hours and weighed. Mean needle weight was expressed as the average weight in grams per 100 needles. The coefficient of variation for the 5 replicates per tree was almost always less than 4%.

To determine foliar nitrogen concentration a standard micro-Kjelhahl procedure was used (Bremner and Mulvaney 1982). Total nitrogen concentration was reported as a percentage per unit of dry (70 C) needle weight.

The interpretation of changes in needle weight, nitrogen concentration, and nitrogen content are explained in a previous technical report (Agreement No. 22-C-INT-46). Based on the graphical analysis installations were classed as: (1) no

response; (2) strong response; (3) blocked, variable and weak response.

Soil samples were air-dried, weighed, passed through a 2-mm sieve, and reweighed to determine coarse fraction. Soil carbon was determined by wet combustion and total nitrogen by a micro-Kjeldahl procedure. Mineralizable soil nitrogen was determined by anaerobic incubation (Powers 1980).

DATA ANALYSIS

Two-year Basal Area Growth

Analysis of covariance was used to evaluate the original experiment; the original experiment was designed to test the influence of urea fertilization on the growth of Douglas-fir within the different geographic regions. Discrete factors considered in the analysis were fertilizer treatment and geographic region. Covariates considered included slope, aspect, site index, an index of tree density (Curtis 1982), total soil nitrogen, initial trees per acre, initial basal area per acre, and initial volume per acre. Interactions between fertilizer treatment and all other factors were also considered. Random effects included were installation (nested within region) and block (nested within installation) in addition to the residual error term. Unnecessary fixed effects were removed using a backwards elimination procedure with a 5% significance criterion.

The dependent variable was the natural logarithm of two-year basal area increment. The log transformation was found to be necessary to obtain a normally distributed dependent variable. A bias correction factor suggested by Baskerville (1972) was used to convert point estimates back into original units.

Predicted Fertilizer Response Compared to Actual Two-year Basal Area Increment

Basal area increment (BAI) was calculated by subtracting 1981 basal area from 1983 basal area after correcting 1981 basal area using covariance analysis. The experimental errors associated with differences in basal area among the six plots within an installation would have confounded the calculation of growth response due to fertilization. Therefore, we adjusted the initial basal areas of each plot (1981 basal area) using the mean basal area of the installation as a concomitant variable. Growth response due to fertilization was calculated by subtracting the two-year BAI of control plots from the two-year BAI of fertilized plots.

Bivariate scatter plots were used to depict the relationship between changes in needle weight and basal area increment. Analysis of variance was used to evaluate if the basal area increment differed among the three predicted response categories.

Modeling Basal Area Growth Following Nitrogen Fertilization Using Site and Stand Factors

Data Tabulation

After examining the relationship between predicted growth response (the Krauss technique) and actual two-year BAI, actual two-year BAI was compared to various site and stand attributes by simple tabulation. The installations exhibiting the best two-year BAI were compared to physiographic region, stand density, mineralizable nitrogen and soil parent material. Similarly, the installations exhibiting the worst two-year BAI were compared to physiographic region, stand density, mineralizable nitrogen and soil parent material. After tabulation, empirical distribution functions (Conover 1971) were built showing the probability of increased BAI on different soil types.

Regression Model

An empirical regression model was formulated to evaluate the influence of fertilization, site and stand factors on basal area growth. The dependent variable was the natural logarithm of two-year BAI, expressed on a per acre basis. BAI was calculated by subtracting, on a plot by plot basis, 1981 basal area from 1983 basal area. (Note that the dependent variable is basal area growth from 1981 to 1983, not annual increment.) Growth data comes from 270 plots (45 installations X 6 plots per installation), however, only 250 plots had complete soil data sets. Therefore, a full complement of data existed for 250

cases. The log transformation was necessary to obtain a normally distributed dependent variable. The bias correction factor suggested by Baskerville (1972) was used to convert point estimates back into original units.

Independent variables were included in the model through a backwards elimination procedure with a 5% significance criterion. Several continuous and class variables, along with fertilizer treatment, were evaluated for their significance in predicting two-year BAI:

Tabulation of variables evaluated for their significance in predicting two-year Douglas-fir basal area increment.

Continuous Variables

Age (plot mean)
Elevation
Azimuth
Slope (%)
Slope-Aspect Transformation (Stage 1976)
Site Index
Density Index (Curtis 1982)
Mean Plot Diameter (dbh)
Trees per Acre, 1981
Plot Basal Area, 1981 (sq ft/ac)
Plot Volume, 1981 (cu ft/ac)
Total Soil Nitrogen (%)
Soil Organic Carbon (%)
Soil Carbon/Nitrogen Ratio
Soil Mineralizable Nitrogen (ppm)
Corrected Mineralizable Nitrogen (ppm)
Soil Coarse Fragments (%)

Class Variables

Fertilizer Treatment
- -control
- -200 lb N/ac
- -400 lb N/ac

Vegetation Series (Daubenmire and Daubenmire 1968)
- -Douglas-fir
- -grand fir
- -western redcedar

Parent Material
- -granite
- -ash/loess (ash and/or loess over meda-sediments or glacial till)
- -basalt/shale
- -till/fill (glacial till, colluvium, valley-fill sediments)

Ash Depth
- -absent
- -shallow (< 3")
- -moderate (3-12")
- -deep (>12")

Soil Depth
- -shallow (<12")
- -moderate (12-24")
- -deep (>24")
- -variable

Pairwise Comparisons and Covariance Analysis

The least squares means procedure of the general linear model (Barr et al. 1982) was used to evaluate fertilizer treatment X soil parent material effects and to test for significant differences among subclass means.

Analysis of covariance was used to illustrate the influence of independent variables, or variable interactions, in the empirical BAI model. Concomitant variables were held at their mean values to illustrate how, for example, fertilizer treatment and soil type interacted to effect BAI.

RESULTS AND DISCUSSION

Two-year Basal Area Growth

The final statistical model contained the following effects: geographical region, installation within region, block within installation, fertilizer treatment, treatment X region, initial basal area per acre, and treatment X initial basal area. All fixed effects were significant at a 5% level. The overall model was highly significant and accounted for over 87% of the total variation in two-year basal area growth.

Northern Idaho showed the largest absolute response to the 200 lb/ac N treatment, with an average increase of 2.92 sq ft/ac over the two year period. Fertilization at 200 lb/ac N produced the largest relative response (36%) in central Washington. Central Washington also exhibited, on the average, the largest absolute (4.04 sq ft/ac) and relative (58%) response to the 400 lb/ac N

treatment (Table 1). Substantial variation in radial growth response occurred within each geographic region as documented below. It is of interest that nitrogen fertilization resulted in significant growth response over the entire Inland Empire. This substantiates the concept that nitrogen is likely to limit the growth of northern Rocky Mountain Douglas-fir in many instances.

Initial tree density was significantly related to the magnitude of growth response but the slope differed with type of treatment. Plot density at the time of treatment was expressed in the model as basal area per acre. Basal area growth was positively related to density, but the slope was higher for control plots than either of the two treatment types. Thus, as density increased the difference in growth between control and fertilized plots lessened. At very high densities, usually greater than 210 sq ft/ac, fertilizer response was predicted by the statistical model to be zero. The interactions between basal area growth and fertilizer treatment are graphed and explained in more detail by Moore (1984).

Predicted Fertilizer Response Compared to Actual Two-year Basal Area Increment

The BAI attributable to fertilization varied substantially among installations within each geographic region (Table 2). For example, in Montana, where average response was low, relative response varied from a high of 54.6% to a low of -11.5% (Table 2). In central Washington, where average response was high, relative response varied from a high of 107.4% to a low of 9.5%.

Table 1. Two-year average adjusted basal area per acre growth increment by treatment and geographic region.[a]

Region	Treatment				
	Control	200 lb/ac N		400 lb/ac N	
	(ft^2/ac)	(ft^2/ac)	(response)[b]	(ft^2/ac)	(response)
north Idaho	9.81A[c]	12.73B	+30%	12.37B	+26%
Montana	7.51A	8.75B	+16%	8.58B	+14%
central Idaho	7.24A	9.31B	+29%	9.78B	+35%
northeast Oregon	5.42A	6.75B	+24%	6.56B	+21%
central Washington	7.00A	9.49B	+36%	11.04C	+58%
northeast Washington	8.79A	10.77B	+23%	10.90B	+24%

[a] Adjusted to a common initial basal area of 128 ft^2/ac

[b] Relative to growth of control plots

[c] Within each row, means followed by the same letter were not significantly different

Table 2. Average fertilizer treatment response for individual installations. Treatment response arranged (descending order) according to relative response within individual geographic regions. (Treatment 2 = 200 lb/ac N, Treatment 4 = 400 lb/ac N)

Installation	Treatment	Region	Two-year Response (sq ft/ac)	Percent Response
240	2	northern Idaho	5.56	52.1
205	4		5.16	50.5
204	4		4.95	45.2
205	2		4.54	42.5
240	4		4.46	37.3
204	2		3.76	34.1
206	2		2.69	24.3
206	4		1.61	13.8
208	2		-0.99	-10.7
208	4		-1.54	-18.9
235	2	Montana	2.15	54.6
235	4		1.8	45.4
233	4		3.32	38.1
232	4		3.48	32.6
232	2		2.87	26.7
231	4		1.89	25.5
238	2		1.84	24.8
233	2		2.01	23.2
231	2		1.36	20.5
238	4		1.12	15.2
237	2		0.41	6.1
236	4		0.09	1.7
234	2		-0.16	-1.5
236	2		-0.14	-2.5
234	4		-0.75	-8.05
237	4		-0.83	-11.5
223	2	central Idaho	5.12	73.9
219	4		4.68	59.1
220	4		2.68	57.8
201	4		3.34	47.4
221	2		2.67	46.5
202	4		2.97	44.8
203	2		2.66	44.5
223	4		3.11	44.3
219	2		3.28	44.1
220	2		1.84	38.9
203	4		1.91	34.7
202	2		1.3	21
222	4		1.71	17.7
221	4		0.69	12.4
201	2		0.41	5.6
222	2		0.42	5

Table 2. cont...

Installation	Treatment	Region	Two-year Response (sq ft/ac)	Percent Response
213	4	northeastern	2.16	53.1
207	2	Oregon	3.18	43.8
212	2		2.5	43.4
212	4		1.68	29.4
213	2		1.2	28.6
207	4		1.68	22
245	2		0.76	10.2
239	2		0.02	0.3
245	4		-0.07	-0.8
244	2		-0.41	-6.6
239	4		-0.92	-9
244	4		-0.61	-10.1
230	4	central	4.96	107.4
227	2	Washington	4.52	88.3
242	4		4.62	83.3
225	4		6.02	74
230	2		3.21	68.6
241	4		6.5	66.8
226	4		3.87	66.1
227	4		3.12	65.3
226	2		2.92	46.3
224	2		3.45	37
224	4		2.98	35.2
228	4		2.17	32
229	4		2.06	25.9
242	2		1.62	25.4
225	2		2.05	22
241	2		1.83	18.1
228	2		0.73	11.2
229	2		0.78	9.5
217	4	northeastern	3.6	47.4
217	2	Washington	2.93	41.5
216	4		2.32	38
210	4		2.24	36.9
209	2		2.38	36.4
210	2		2.27	35.5
215	2		3.71	34.4
211	2		3.1	34.3
211	4		4.78	33.2
216	2		1.68	29.8
209	4		1.81	29.2
214	4		1.9	16.3
215	4		1.57	15
218	4		0.88	9.6
214	2		0.85	8.1
243	2		0.62	7.8
243	4		0.44	5.1
218	2		-0.39	-4.1

The variation in BAI attributable to fertilization was not related to changes in needle weight or to the predicted response categories. Figure 1 shows that no overall trend existed between increases in needle weight one year following fertilization and two-year BAI. Similar scatter diagrams for individual geographic regions are presented in Appendix A. Figure 2 shows there was no relationship between predicted response (the Krauss or Weetman technique) and actual two-year BAI. Analysis of variance confirmed the results depicted in Figure 2. We concluded that the Krauss (or Weetman) foliar diagnostic technique could not be used as a practical method of predicting fertilizer response. Thus, the null hypothesis that there is no relationship between predicted fertilizer response and two-year BAI was accepted on the basis of our data. This rendered our second initial hypothesis uninteresting.

Two explanations for the failure of the foliar diagnostic technique seem plausible. First, the technique assumes that changes in needle area (weight) are directly related to growth response. Implicit in this assumption is the idea that in order for growth to increase, leaf area must expand. There is considerable evidence to suggest that nitrogen fertilization increases leaf area which, in turn, results in increased growth (Leyton 1957, Keay et al. 1968, Brix and Ebell 1969, Ebell 1972, Weetman and Algar 1974). The "pipe model" theory of Douglas-fir growth would also support the notion that increased basal area growth must be related to increased leaf area (Waring et al. 1982). However, as Brix and Ebell (1969) show, nitrogen

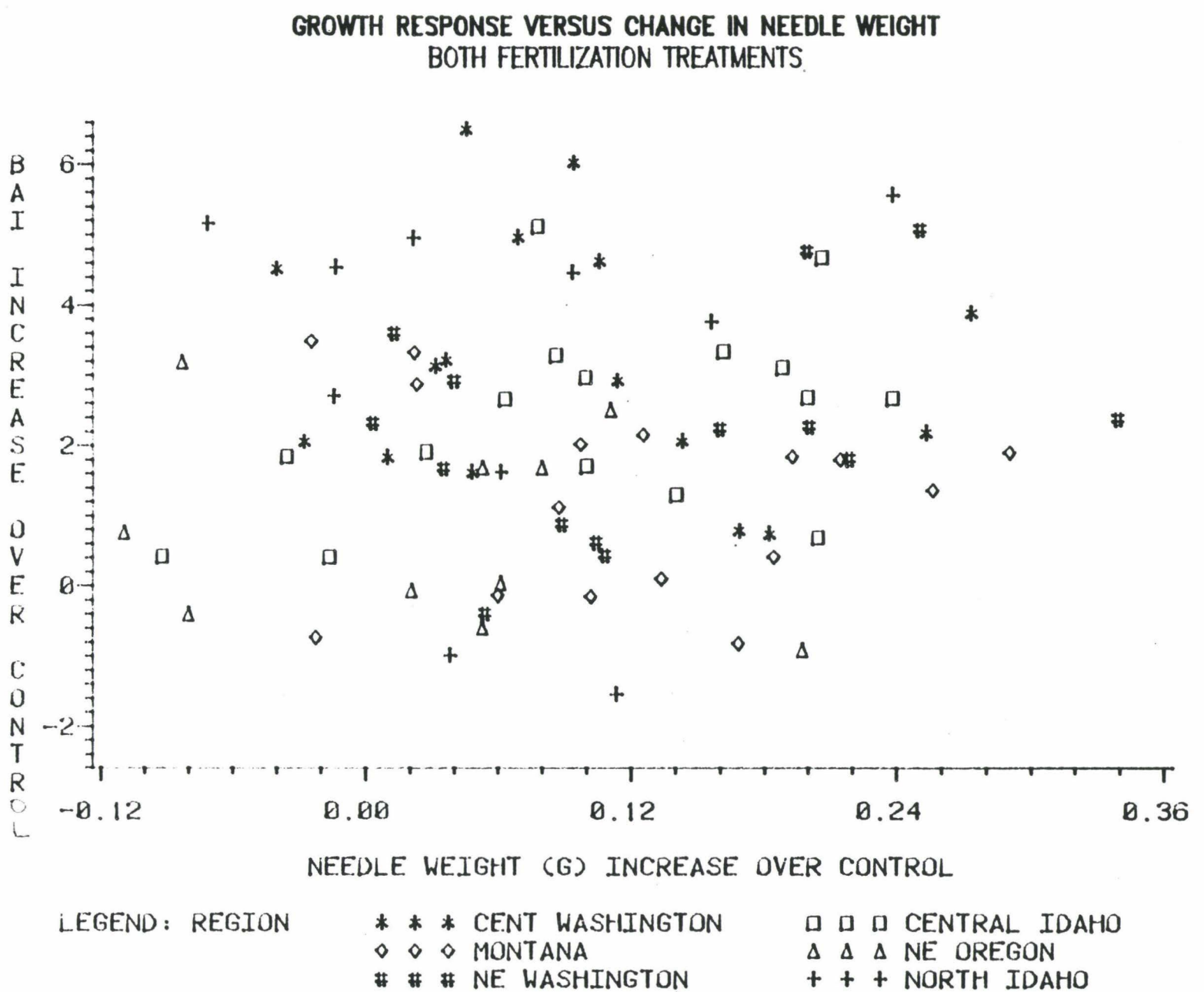

Figure 1. Relationship between two-year basal area increment (ft 2/ac) and change in needle weight.

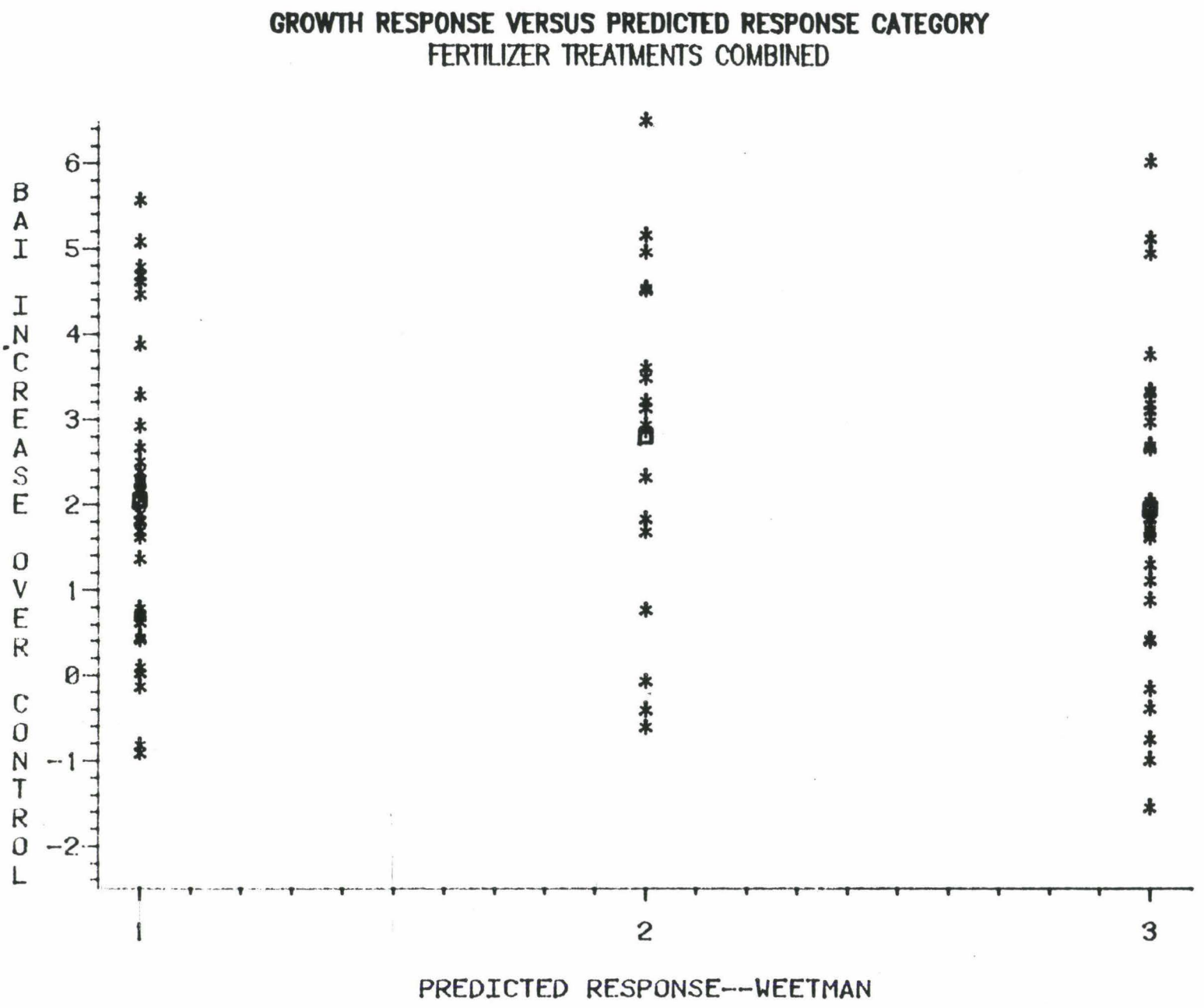

Figure 2. Relationship between two-year basal area increment (ft 2/ac) and predicted fertilizer response category. (1= no response, 2= strong response, 3= variable response).

fertilization can also increase photosynthetic rate in Douglas-fir. An increase in photosynthetic rate due to fertilization could account for the poor correspondence between predicted response and actual growth.

Seasonal differences in needle weight could have also confounded the relationship between predicted response and actual growth. Smith et al. (1981) reported a sharp drop in Douglas-fir needle weight (an approximately 40% decline) during October in the Cascade Mountains. Presumably the drop in needle weight is due to the export of carbohydrates from the needles before the onset of winter. Their data show relatively constant needle weights from November through March. It is possible a portion of our needle sampling period, September through December, occurred when needle weights were rapidly changing.

Modeling Basal Area Growth Following Nitrogen Fertilization Using Site and Stand Factors

Failure of the foliar diagnostic technique resulted in revaluation of our baseline data. Two-year BAI enabled sorting of site and stand factors according to fertilizer response and provided insightful results. Installations exhibiting relatively large increases in basal area growth due to fertilization tended to occur on deep loamy soils or soils with volcanic ash sediments (Table 3). Their basal areas were not high, averaging 122 sq ft/ac and their soils had relatively low nitrogen mineralization potential, averaging 38 ppm (Table 3). A simple empirical distribution function illustrated the high probability of fertilizer response on soil with at least 6 inches of

Table 3. Site and stand attributes of installations exhibiting relatively large increases in two-year basal area growth due to nitrogen fertilization.

Installation	Physiographic Region	2-yr. Growth Response[A] 200 lb/ac Abs. (ft ^{2}/ac)	200 lb/ac Rel.	400 lb/ac Abs. (ft ^{2}/ac)	400 lb/ac Rel.	Basal Area (ft ^{2}/ac)	Ave. Min. -N (ppm)	Soil Parent Material
204	N. Idaho	3.8	34%	4.9	45%	105	30	Thick Ash over metasediments
205	N. Idaho	4.5	43%	5.2	51%	111	34	Thick Ash over metasediments
240	N. Idaho	5.6	52%	4.4	37%	149	47	Thick Ash over metasediments
232	Montana	2.9	27%	3.5	32%	138	70	Shallow, rocky glacial till
235	Montana	2.1	55%	1.7	45%	110	52	Rocky silt loam, valley-fill sediments
219	C. Idaho	3.2	44%	4.6	59%	127	57	Deep silt loam-basalt
223	C. Idaho	5.1	74%	3.1	44%	111	35	Deep silt loam-basalt
224	NE Oregon	3.4	37%	2.9	35%	155	35	--
225	C. Wash.	2.0	22%	6.0	74%	110	20	Deep silt loam-basalt
226	C. Wash.	2.9	46%	3.9	66%	88	17	Deep silt loam-basalt
227	C. Wash.	4.5	88%	3.1	65%	102	25	Rocky silt loam (Ash) over basalt
211	NE Wash.	5.1	34%	4.7	33%	171	31	Ash/Loess mixed with granitic colluvium
217	NE Wash.	2.9	41%	3.6	47%	113	42	Volcanic Ash over Glacial till
N = 13		$\bar{x}$ = 3.6	46%	4.0	43%	122	38	

[A]Adjusted only for average installation basal area. Growth is relative to control plots.

volcanic ash (Figure 3).

In contrast, installations showing little or no response to nitrogen fertilization tended to occur on shallow-rocky soil, or on glacial parent materials (Table 4). Stand density was higher in nonresponding stands, as was soil nitrogen mineralization potential (Table 4). The simple tabulation of baseline data suggested that moisture availability throughout the growing season might limit nitrogen fertilizer response. The obvious trends in site and stand conditions also suggested that BAI following fertilization could be modeled using site and stand factors.

The final regression model contained the following effects: fertilizer treatment, soil parent material, volcanic ash depth, soil depth, soil total nitrogen, site index, mean stand dismeter, initial basal area, soil total nitrogen X soil parent material, mean stand diameter X soil parent material, mean stand diameter X volcanic ash depth, initial basal area X volcanic ash depth, fertilizer treatment X soil parent material, and initial basal area X fertilizer treatment. The overall model was highly significant and explained 71% of the two-year basal area growth across all geographic regions and fertilizer treatments. The model could be written as:

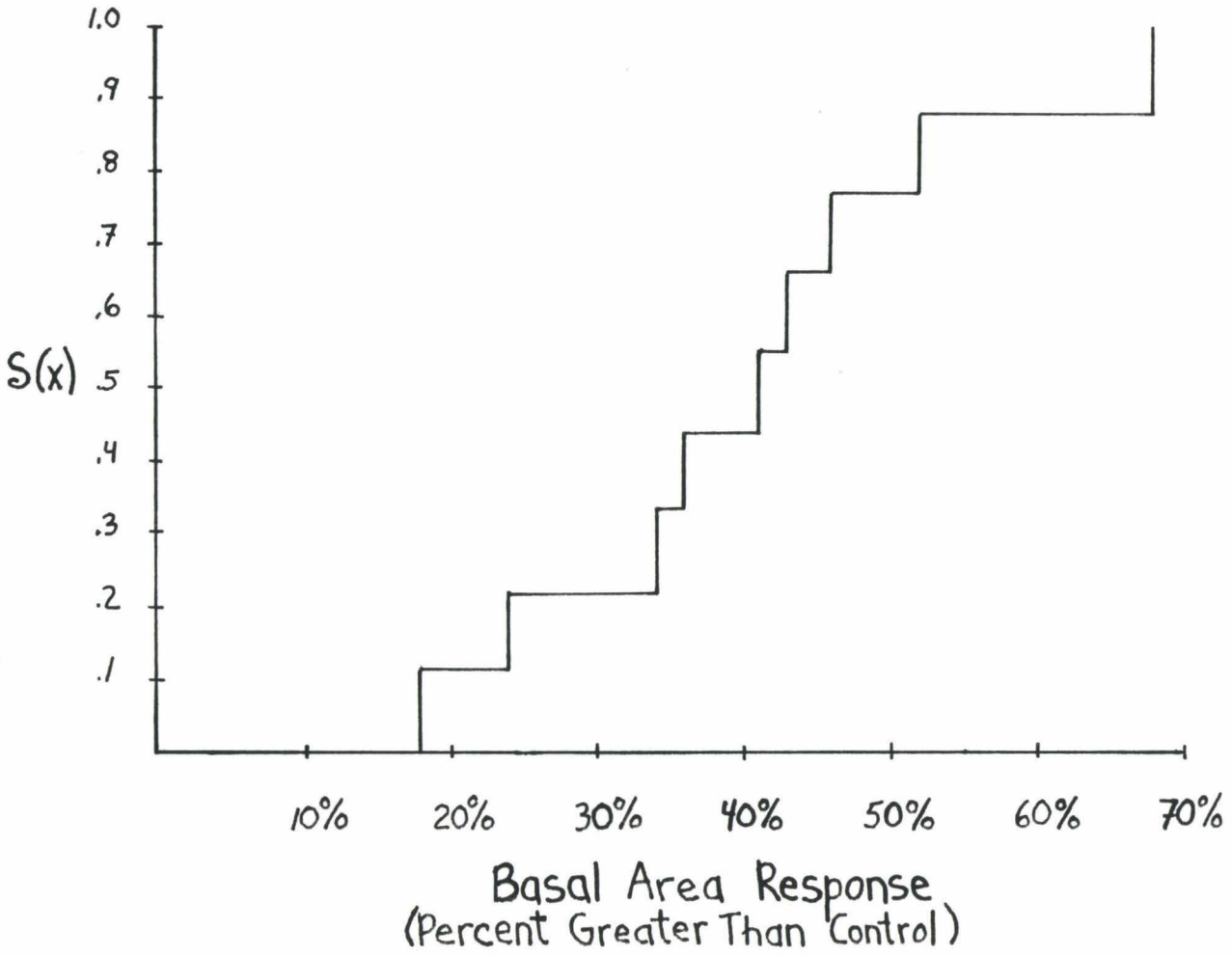

Figure 3. Empirical distribution function. (S(x)) of relative growth response on soils with at least 6 inches of volcanic ash.

Table 4. Site and stand attributes of installations exhibiting little or no increase in two-year basal area growth due to nitrogen fertilization.

Installation	Physiographic Region	2-yr. Growth Response[A] 200 lb/ac Abs. (ft ^{2}/ac)	200 lb/ac Rel.	400 lb/ac Abs. (ft ^{2}/ac)	400 lb/ac Rel.	Basal Area (ft ^{2}/ac)	Ave. Min. -N (ppm)	Soil Parent Material
208	N. Idaho	-1.0	-10%	-1.5	-18%	189	58	Shallow loess over meta-sedimentary bedrock
234	Montana	-0.2	-1%	-0.7	-8%	131	68	Shallow, extremely rocky soil derived from glacial deposits
236	Montana	-0.1	-2%	0.1	2%	169	75	Very shallow, extremely rocky soil derived from valley fill
237	Montana	0.4	6%	-0.8	-11%	149	66	Shallow, extremely rocky soil derived from glacial till
222	C. Idaho	0.4	5%	1.7	18%	138	43	Shallow, rocky silt loam over basalt
239	NE Oregon	0.1	0%	-0.9	9%	183	71	Shallow, rocky soil over basalt
244	NE Oregon	-0.4	-7%	-0.6	-10%	272	72	Deep, rocky soil over granite bedrock
245	NE Oregon	0.8	10%	-0.1	-1%	191	68	Shallow, very rocky silt loam over basalt
214	NE Wash.	0.9	8%	1.9	16%	91	46	---
218	NE Wash.	-0.4	-4%	0.8	10%	94	36	Very rocky glacial till over gneiss bedrock
243	NE Wash.	0.6	8%	0.4	5%	129	81	Depth variable, rocky loess over glacial till
n = 11		$\bar{x}$ = 0.1	1%	0.03	-1%	158	62	

[A]Adjusted only for average installation basal area. Growth is relative to control plots.

$$\ln(BAI) = u(ijkl) - .00013399(\text{total soil nitrogen}) + .00820387(\text{site index}) + .04179352(\text{mean stand diameter}) + .00093125(\text{initial basal area})$$

where i denotes the parent material class
j denotes the ash depth class
k denotes the soil depth class
l denotes the fertilizer treatment class

Parameter estimates for the interaction terms are presented in Appendix B.

We do not advocate using the above model to predict Douglas-fir basal area growth. However, constructing a model to predict basal area growth of Douglas-fir which includes specific rates of fertilization and site and stand factors as independent variables seems realistic. The above model should be refined, tested against an independent data set, and the basal area growth of the fertilizer trials should be monitered over a longer time period.

An important aspect of the model is that most of the factors can be relatively easily estimated in the field. Personnel could be trained to recognize rock types, soil depth and presence of volcanic ash. It seems realistic to believe a relatively simple and efficient field procedure could be devised to collect the observations necessary to calibrate a model.

The most significant aspect of the research project is documentation of the important role soil plays in controlling Douglas-fir basal area growth and response to nitrogen fertilization. We have tried to explain some of the soil effects and interactions between independent variables using pairwise comparisons and covariance analysis.

Two-year BAI of control plots differed according to soil parent material. Arranged in descending order, the growth of control plots was till/fill > ash/loess > basalt/shale > granite. Growth on granitic soils was always significantly less than growth on other parent materials. Till/fill control plots grew significantly more than those growing on basalt/shale or granite. No significant differences in control growth occurred among till/fill and ash/loess parent materials.

The interaction between fertilizer treatment and soil parent material was most interesting. Fertilization had no significant effect on till/fill soils (Figure 4). Application of 200 lb/ac N resulted in highly significant growth gains on ash/loess and basalt parent materials, and marginally significant ($p=.06$) gains on granitic soils (Figure 4). Application of 400 lb/ac N resulted in highly significant growth gains on ash/loess, basalt and granite (Figure 4). When the 200 lb/ac vs. 400 lb/ac application rates were compared, significant increases in growth only occurred on ash/loess parent materials.

The interaction between initial basal area and soil type shows that different soil types support inherently different levels of basal area growth (Figure 5). Notice that the deep ash/loess, thin ash/loess, and thin ash/basalt soil types have slopes that are increasing at higher levels of stocking (Figure 5). These soils, which have relatively high moisture holding capactiy, support proportionally greater basal area growth at high initial basal areas when compared to the other soil types. Leak (1981) discussed the influence of site quality on stocking for eastern

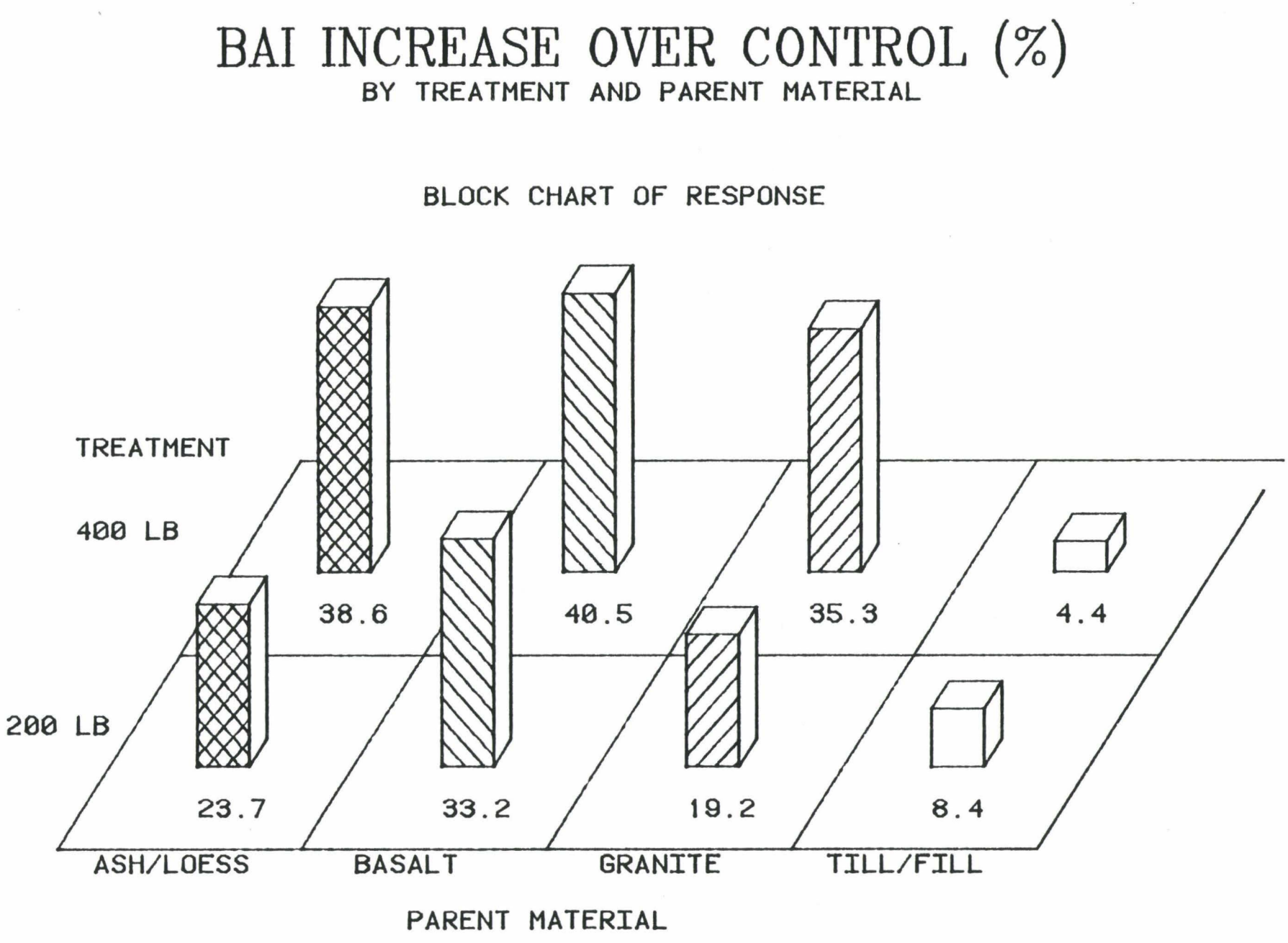

Figure 4. Amount of basal area gain according to level of nitrogen amendment and soil parent material.

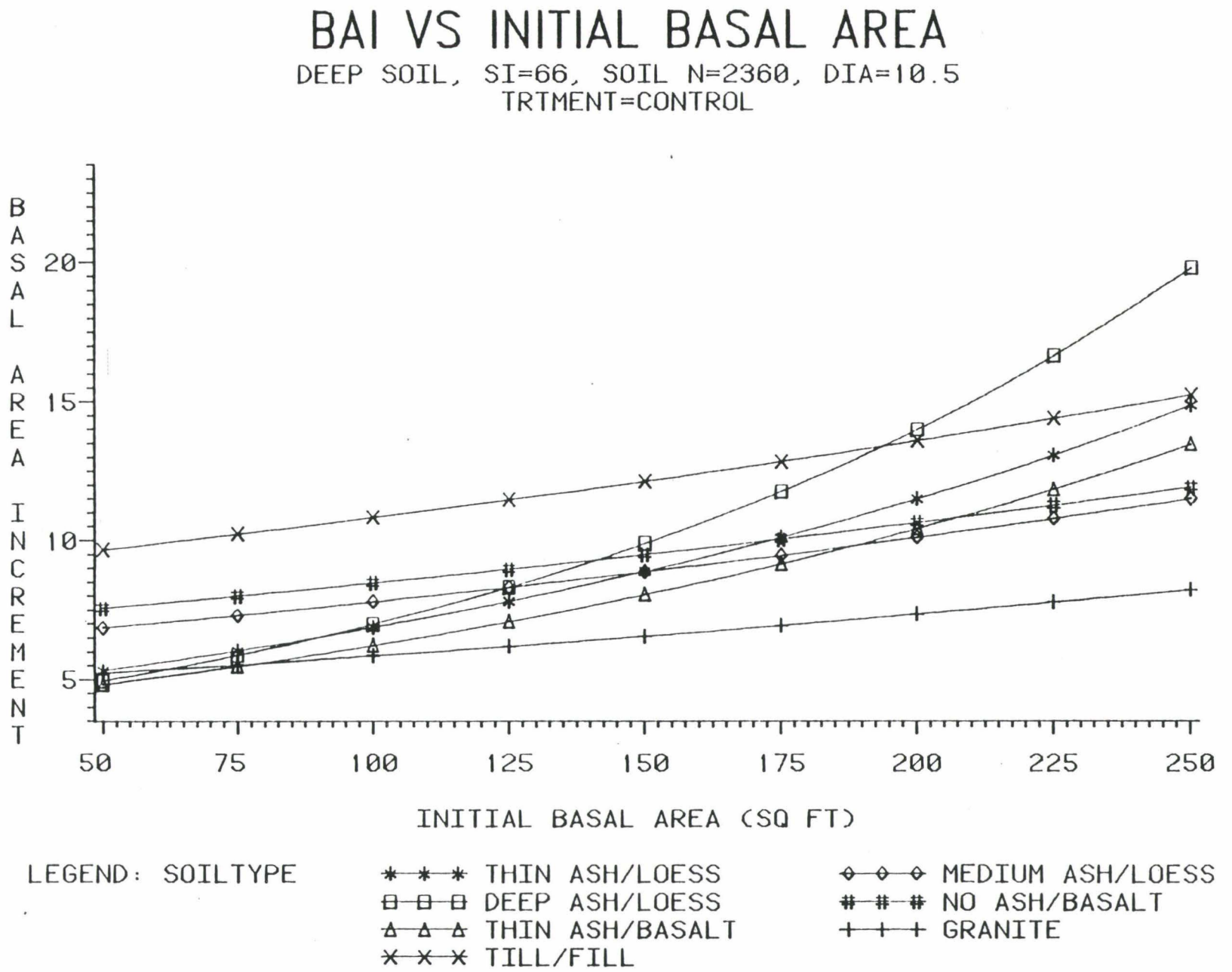

Figure 5. The interaction between initial basal area and soil type and its influence on two-year basal area increment (ft 2/ac) of control plots.

forests and suggested the assumption that normal stocking occurs over a wide range of site quality is invalid. Is it possible that soils with higher moisture holding capacity can maintain higher levels of maximum stocking?

Figure 6 depicts the interaction between initial basal area and fertilizer treatment for basalt soils with no ash cap. Notice that at the highest basal areas the curves are on an intersection trajectory. The same relationship is apparent for granitic soils as shown in Figure 7. In contrast, Figure 8 shows the interaction between fertilizer treatment and initial basal area on deep ash/loess soils. Notice that the slopes differ from Figures 6 and 7, and also that the 400 lb/ac curve is estimated to intersect with the control curve at higher levels of stocking. On deep ash/loess soils what would happen if 600 lb/ac N were applied to stands carrying 250 sq ft/ac of basal area?

Figures 6, 7, and 8 all show that at low basal areas 200 lb/ac N produces about the same growth gain as 400 lb/ac N. But at high levels of stocking, 400 lb/ac N produces a larger growth response compared to the 200 lb/ac treatment (Figures 6, 7, 8). Thus, it often appears that at high levels of stocking 200 lb/ac N is not enough nitrogen to maximize the growth of the stand. The interactions between stocking and soil type, and fertilizer treatment and soil type should be studied further.

Figure 9 is a summary of the effects of volcanic ash depth, soil parent material, and fertilizer treatment on two-year BAI. The

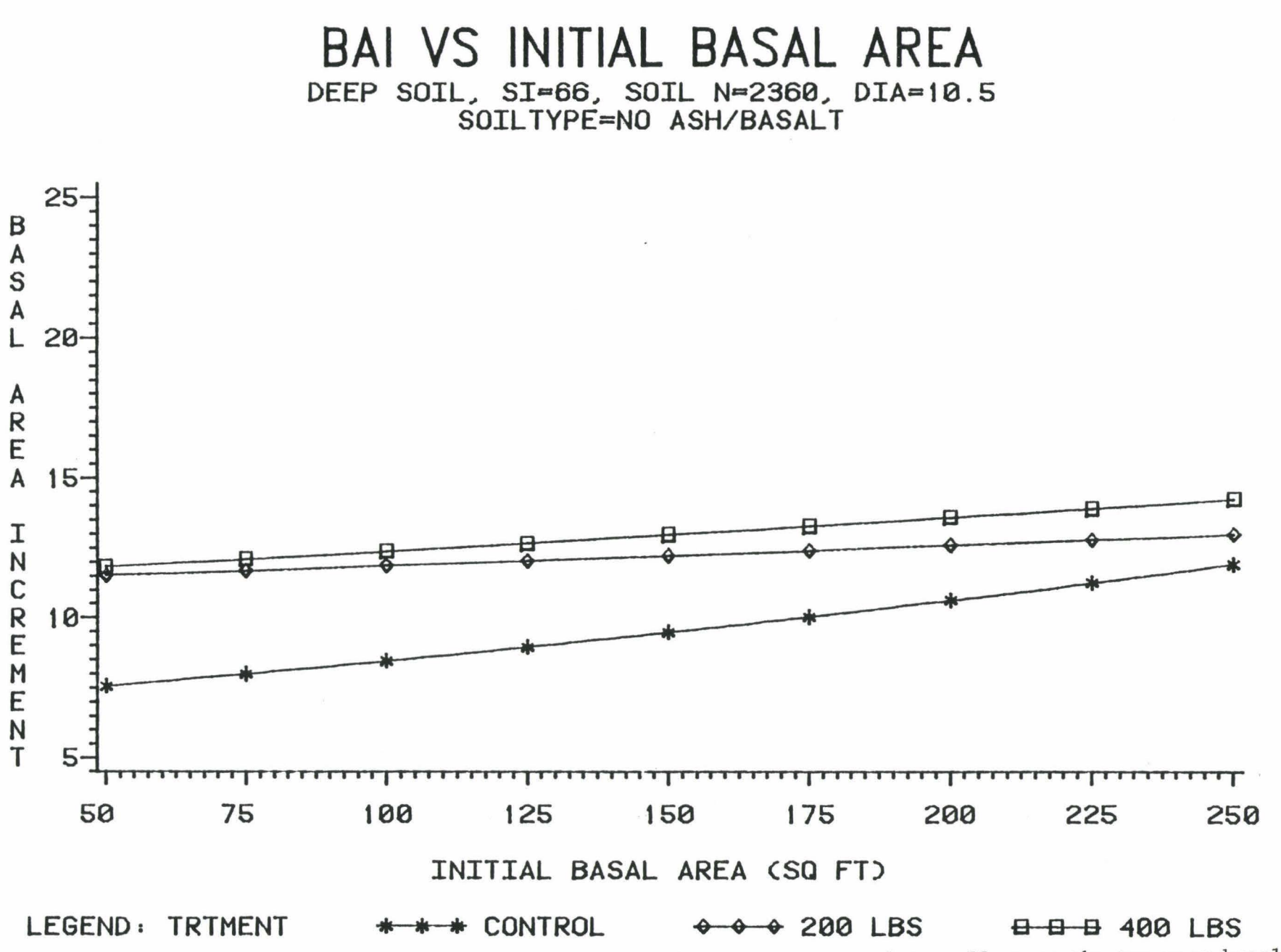

Figure 6. The interaction of initial basal area with fertilizer treatment and its effect on the two-year basal area increment (ft ^{2}/ac) of Douglas-fir growing on basalt soil.

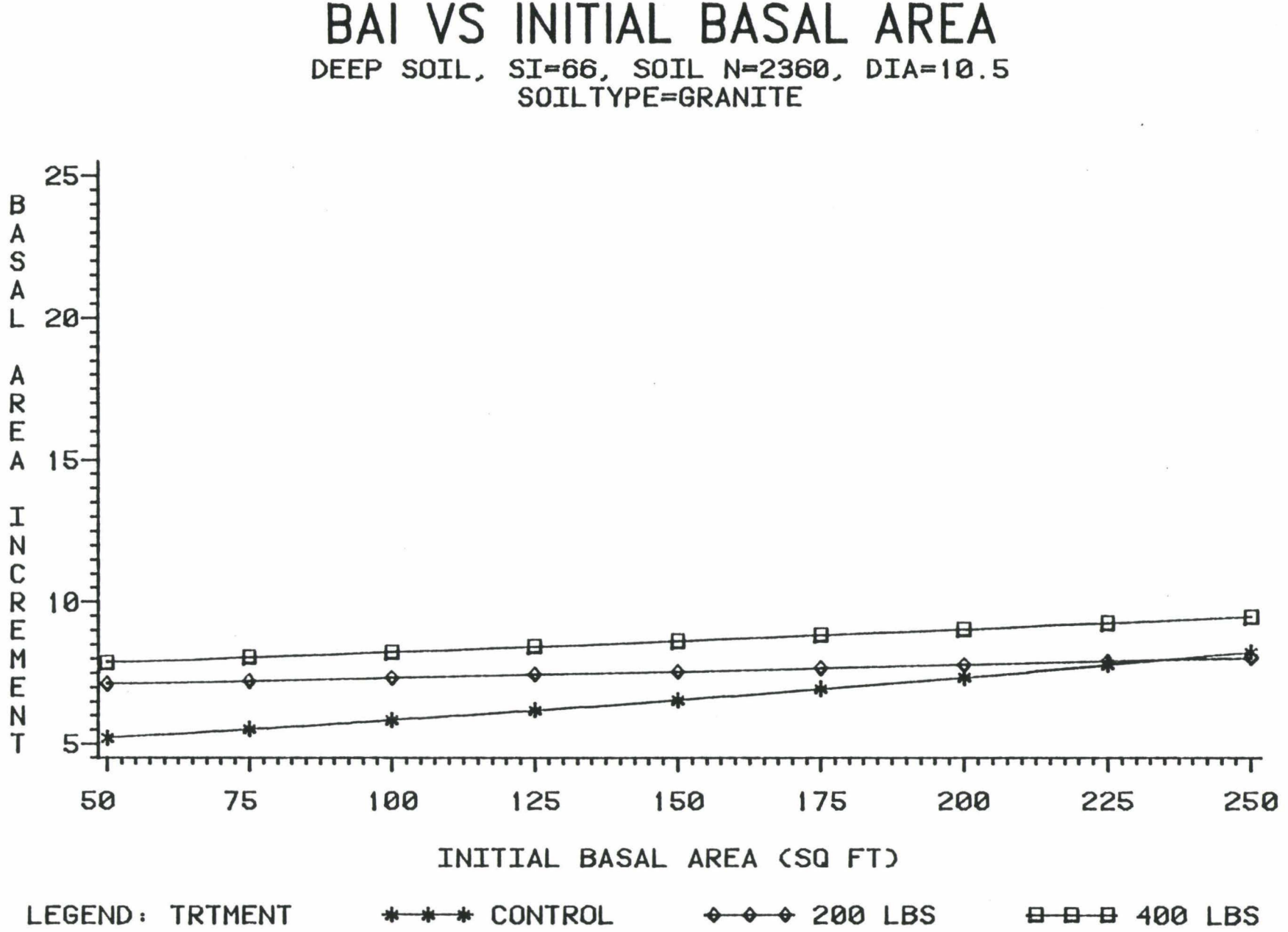

Figure 7. The interaction of initial basal area with fertilizer treatment and its effect on the two-year basal area increment (ft^2/ac) of Douglas-fir growing on granite soil.

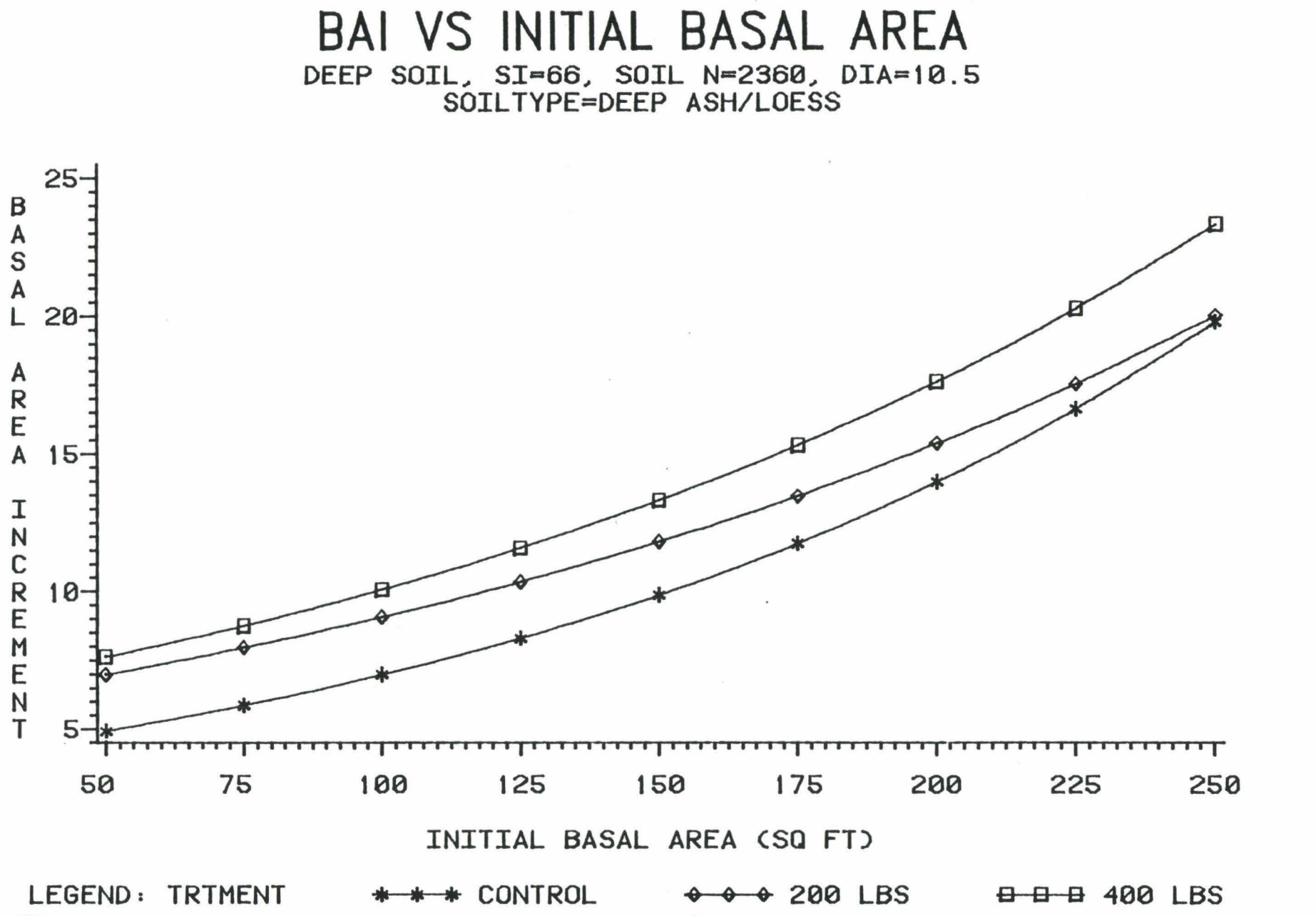

Figure 8. The interaction of initial basal area with fertilizer treatment and its effect on the two-year basal area increment (ft ^{2}/ac) of Douglas-fir growing on deep ash/loess soil.

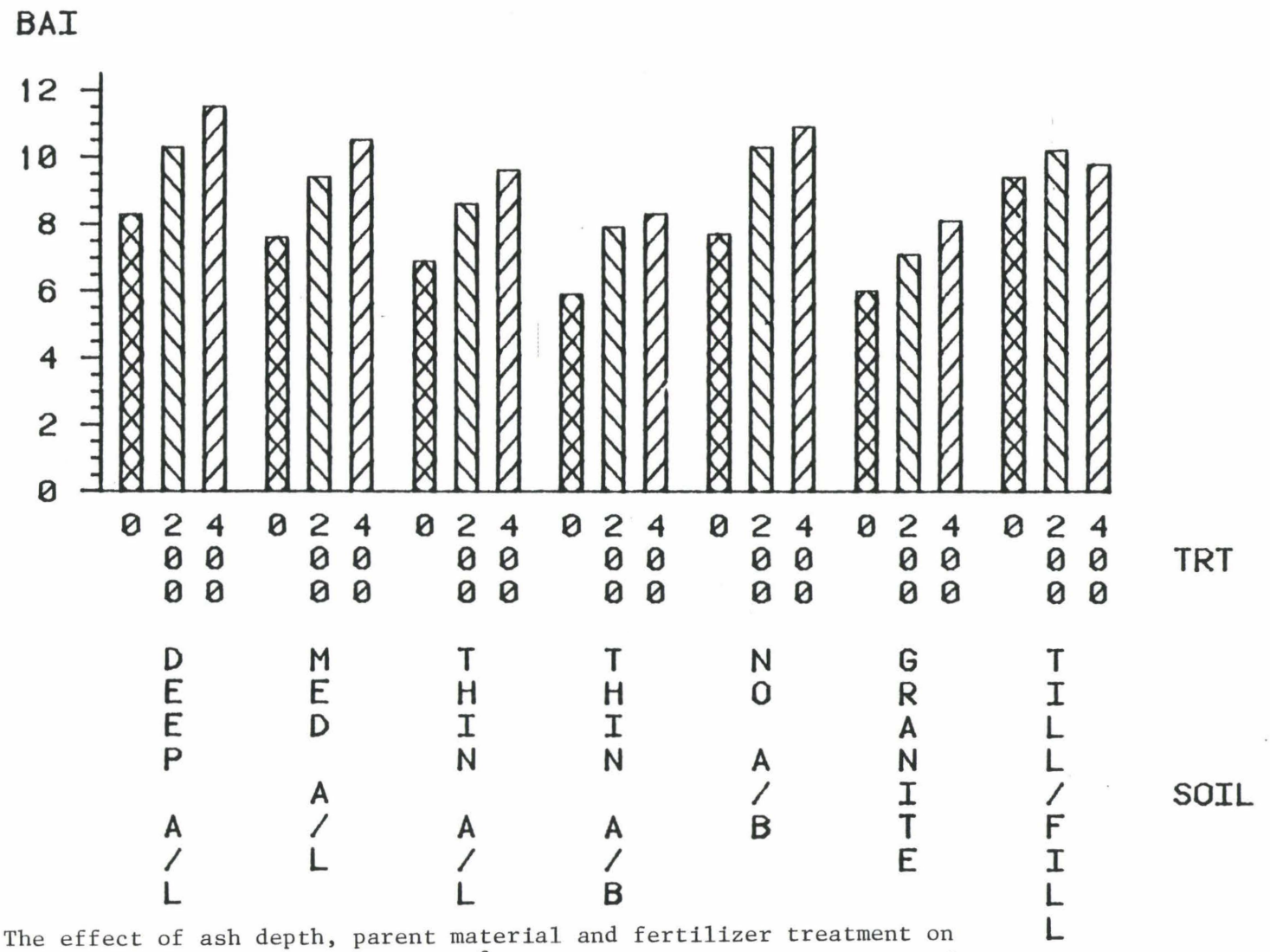

Figure 9. The effect of ash depth, parent material and fertilizer treatment on two-year basal area increment (ft ^{2}/ac) of Douglas-fir. (A/L = ash/loess, A/B = ash/basalt)

seven soil types are the only combinations of class variables observed. The figure clearly shows the interaction between ash depth and parent material. For example, thin ash/loess plots grew more and responded better to fertilizer than thin ash/basalt soils (Figure 9). Growth on granitic soils can be improved by fertilization, but not as significantly as growth on basalt (Figure 9). Soils with a deep cap of volcanic ash hold the most promise of increasing growth through fertilization and seem to respond comparatively well to the highest level of nitrogen application.

SUMMARY AND CONCLUSIONS

Nitrogen fertilization significantly increased the two-year basal area increment of Douglas-fir throughout the Inland Empire. This study clearly shows that Douglas-fir ecosystems of the northern Rocky Mountain region can be added to the list of other temperate forest ecosystems whose growth is nitrogen limited. Such a result is not surprising considering the overwhelming evidence that growth of temperate and boreal ecosystems of the northern hemisphere is often nitrogen limited (Vitousek 1982).

Significant variation in response to nitrogen fertilization occurred within each of the six geographic regions studied (Table 2). Variation in response was not related to changes in needle weight or to predicted fertilizer response category. We conclude that the Krauss (or Weetman) foliar diagnostic technique is not a practical method for predicting response to fertilization. This is particularly true in light of the fact that response to

fertilization may be modeled using site and stand attributes more easily and efficiently measured than changes in needle weight.

Soil clearly influences Douglas-fir basal area growth and response to nitrogen fertilization. Inherent rates of growth differ among parent materials. Granitic soils, which presumably have the lowest moisture holding capacity, support the slowest rates of basal area growth.

Soil parent material and fertilizer treatment interact and knowledge of this interaction can be used to formulate management guidelines. Deep volcanic ash soils over loess exhibit relatively large fertilizer gains. They also respond well to the highest levels of nitrogen amendment. Deep basalt derived soils also respond well to fertilization, but the lower rate of application is recommended. Growth on granitic soils can be improved through fertilization, but gains are not as great as on ash/loess and basalt soil. Glacial soils show no apparent response to fertilization after two years. Their behavior remains an unexplained facet of our research.

Volcanic ash is an important soil resource and should clearly be recognized as such. Its depth significantly influences inherent rates of diameter growth (Figure 9). Furthermore, response to nitrogen fertilization is greatest on soils with a deep ash cap. Deep ash soils show the greatest potential for intensive nitrogen management of all the soils we studied in the Inland Empire.

It appears feasible to build models of basal area growth that include nitrogen fertilization as a factor. Our model accounted

for 71% of the overall two-year variation in the diameter growth of Douglas-fir throughout the Inland Empire. Soil factors were important components of the model along with stand attributes. Basal area and mean stand diameter significantly interacted with soil parent material and depth of volcanic ash.

Results strongly implicate moisture availability as a factor that regulates the inherent growth Douglas-fir and its response to nitrogen fertilization. The best baseline growth and greatest response to fertilization occurred on soils with the greatest moisture holding capacity. The significant interaction between basal area and fertilizer response also has moisture implications. At high levels of stocking the available storage capacity of the soil would be depleted earlier in the growing season. Lack of available moisture late in the summer may explain why stands with high basal areas show relatively little response to fertilization when compared to control plots. This may also explain why deep ash soils with high moisture holding capacity exhibit good fertilizer response at high basal areas. The interaction between moisture and nitrogen availability is the most promising area for future research and would provide a more basic understanding of the regulation of temperate tree growth.

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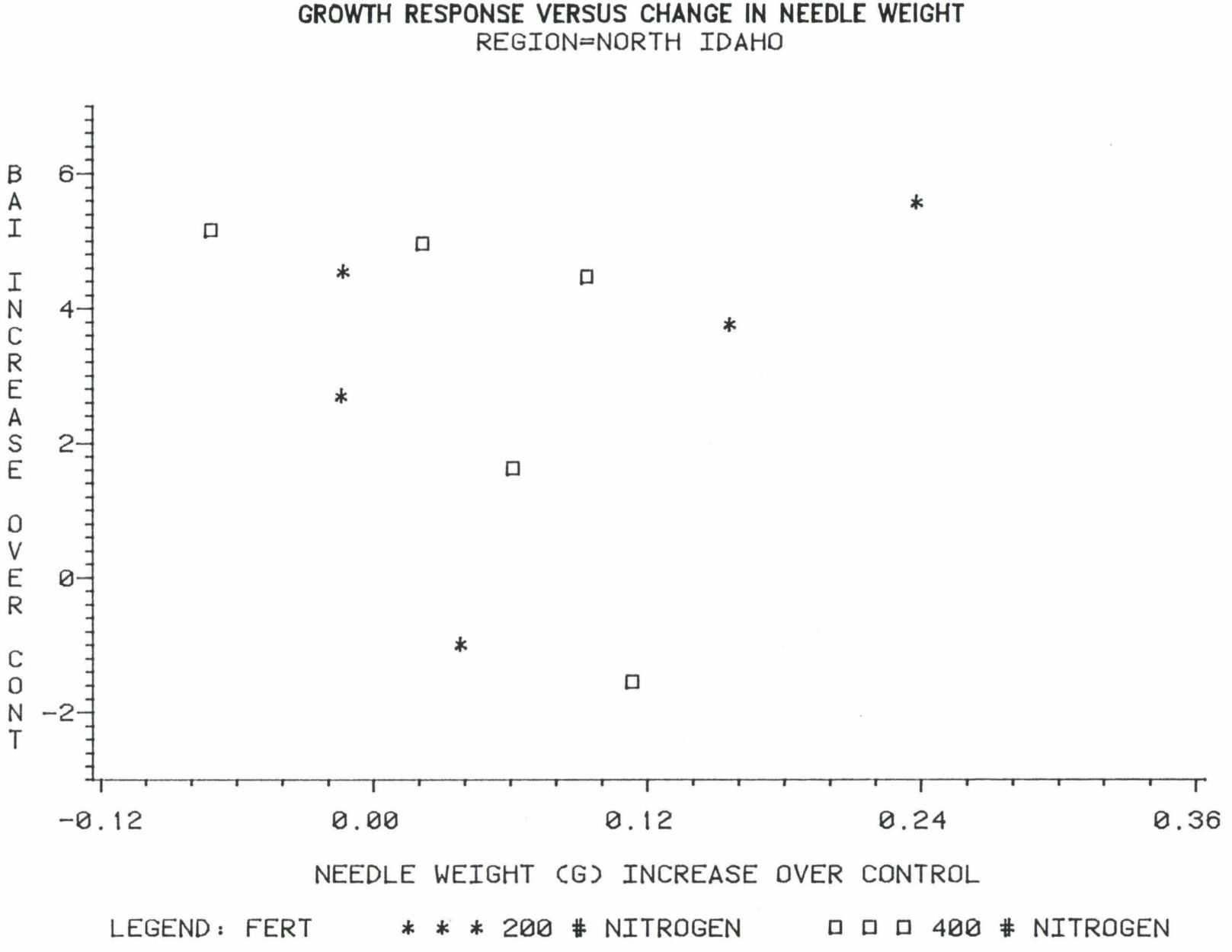
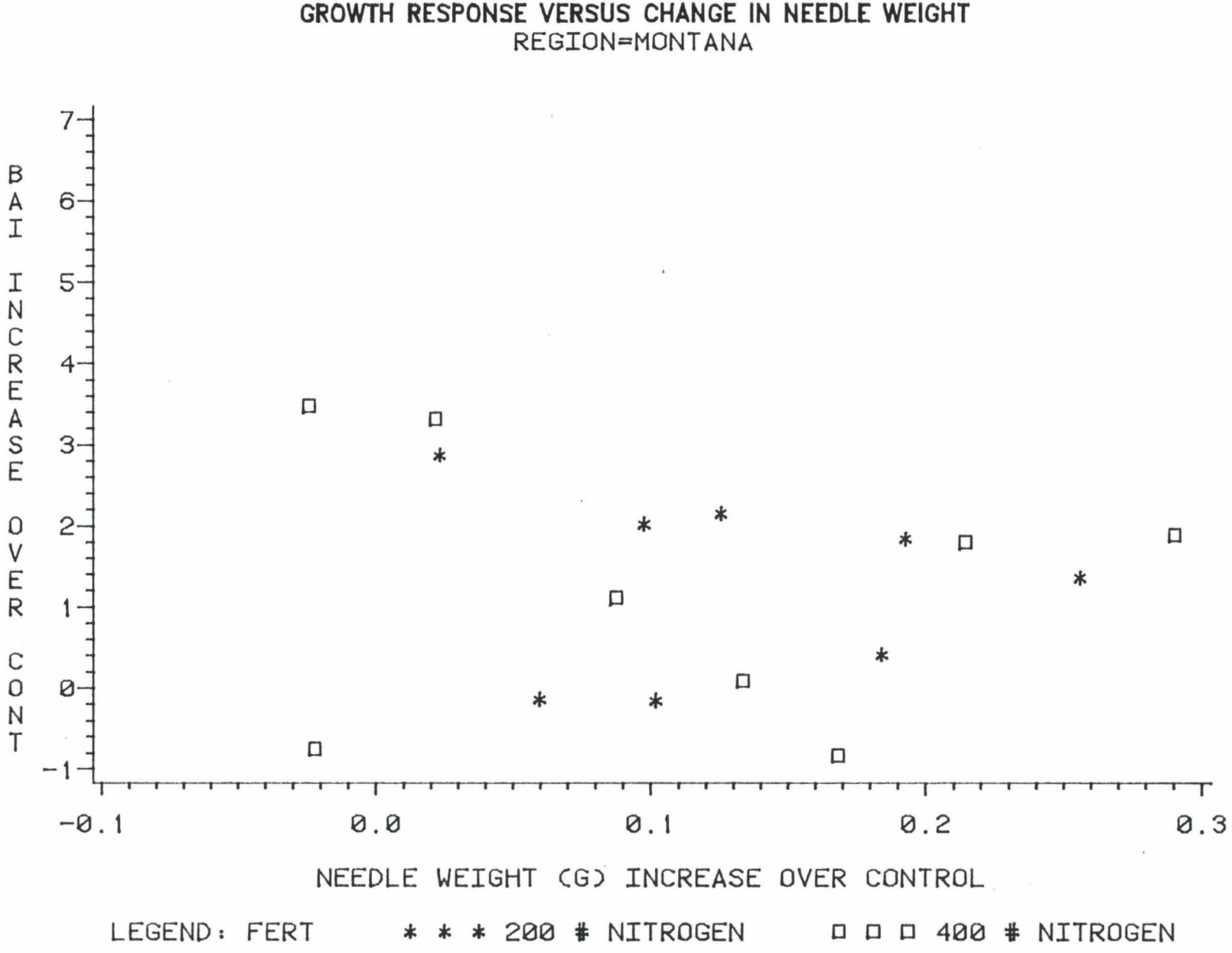
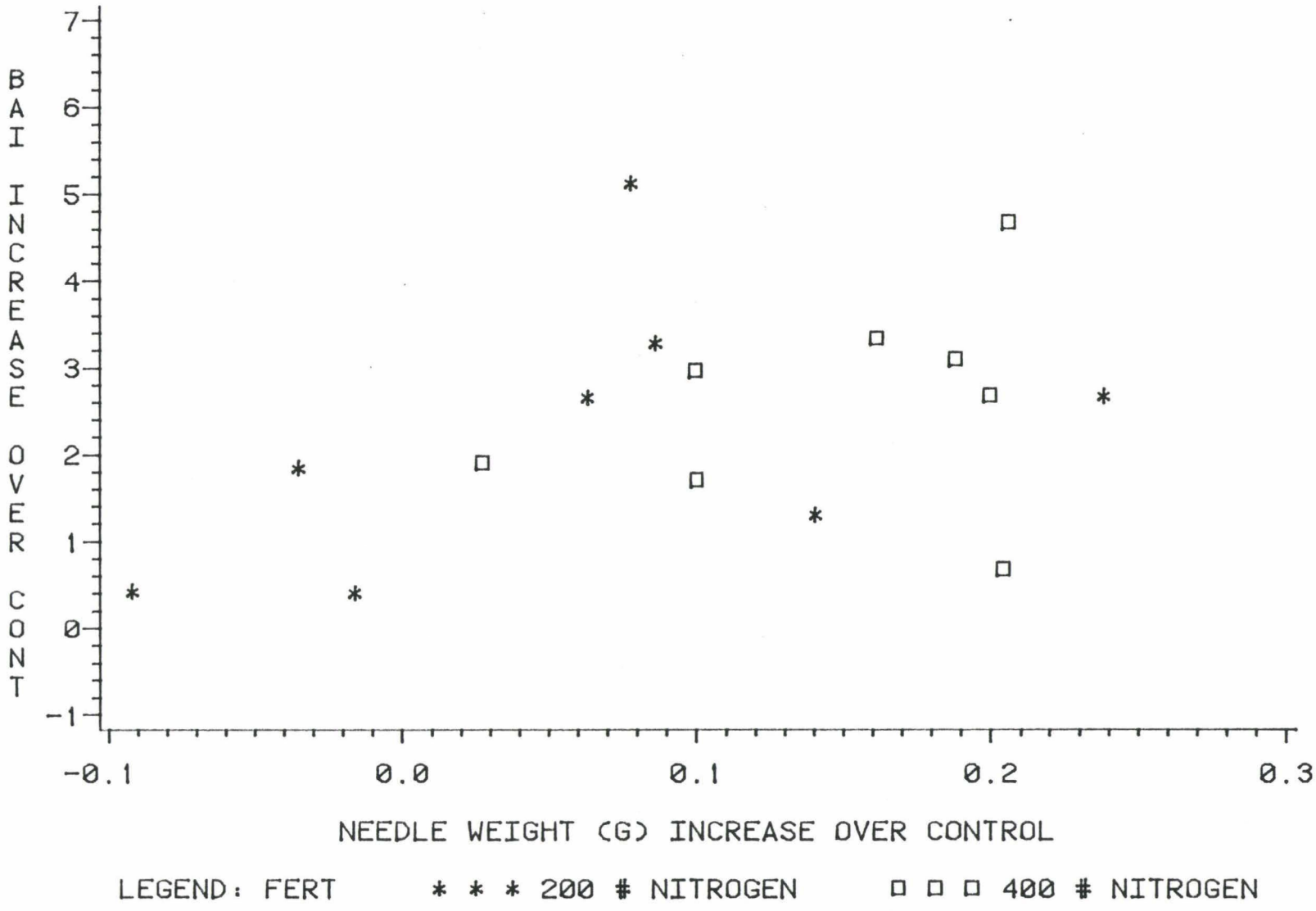
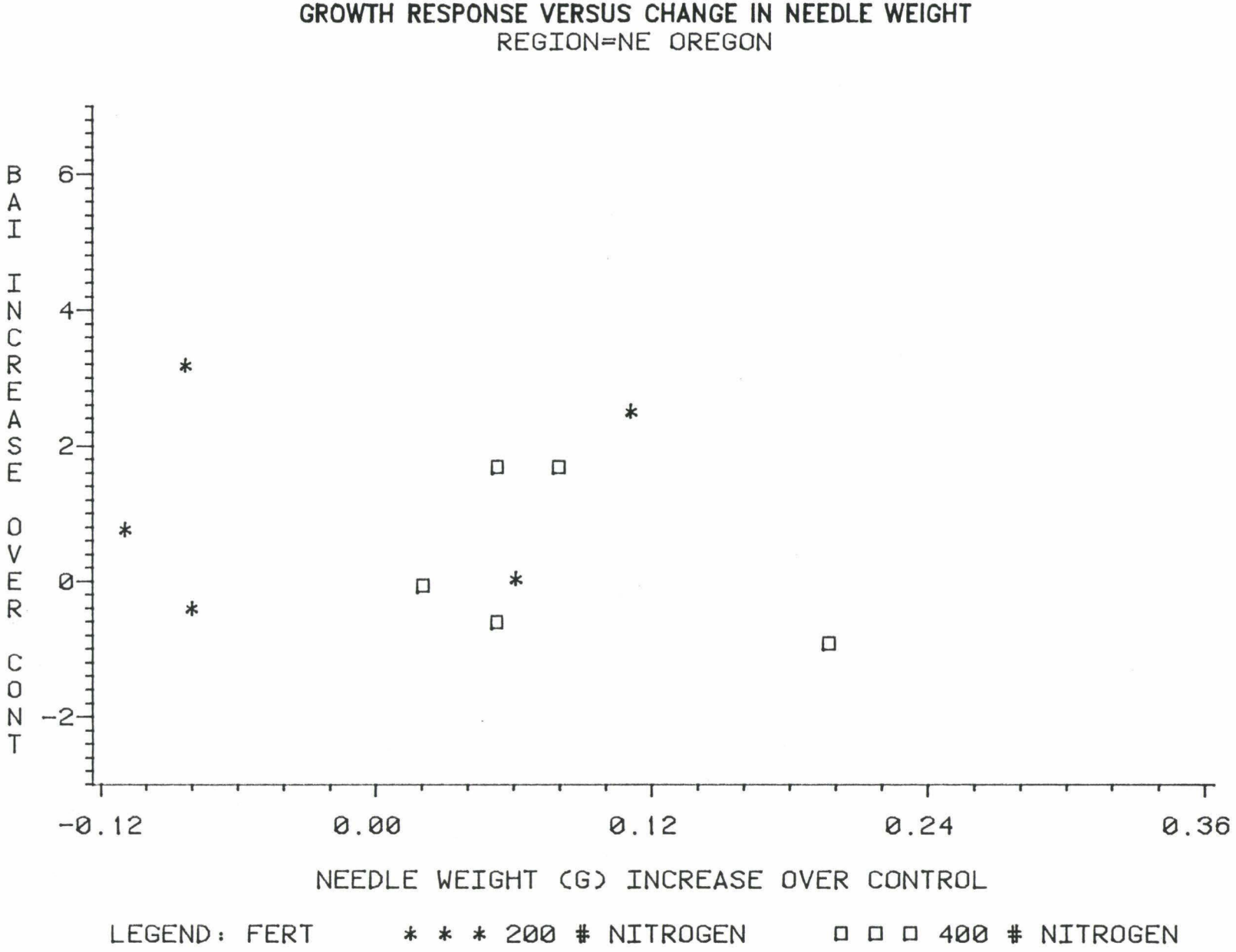
APPENDIX A

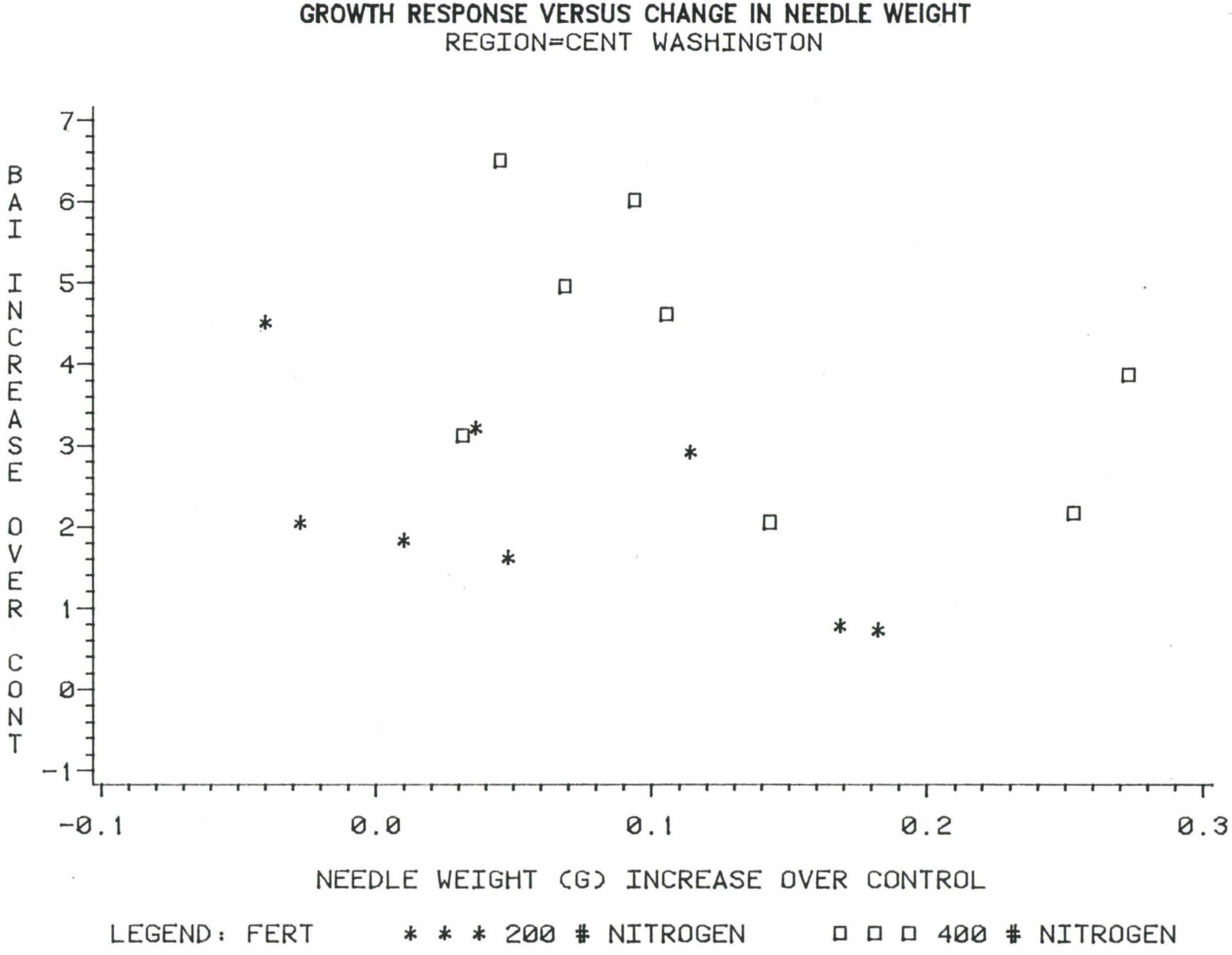
Relationship between needle weight and basal area increment by geographic region and fertilizer treatment.

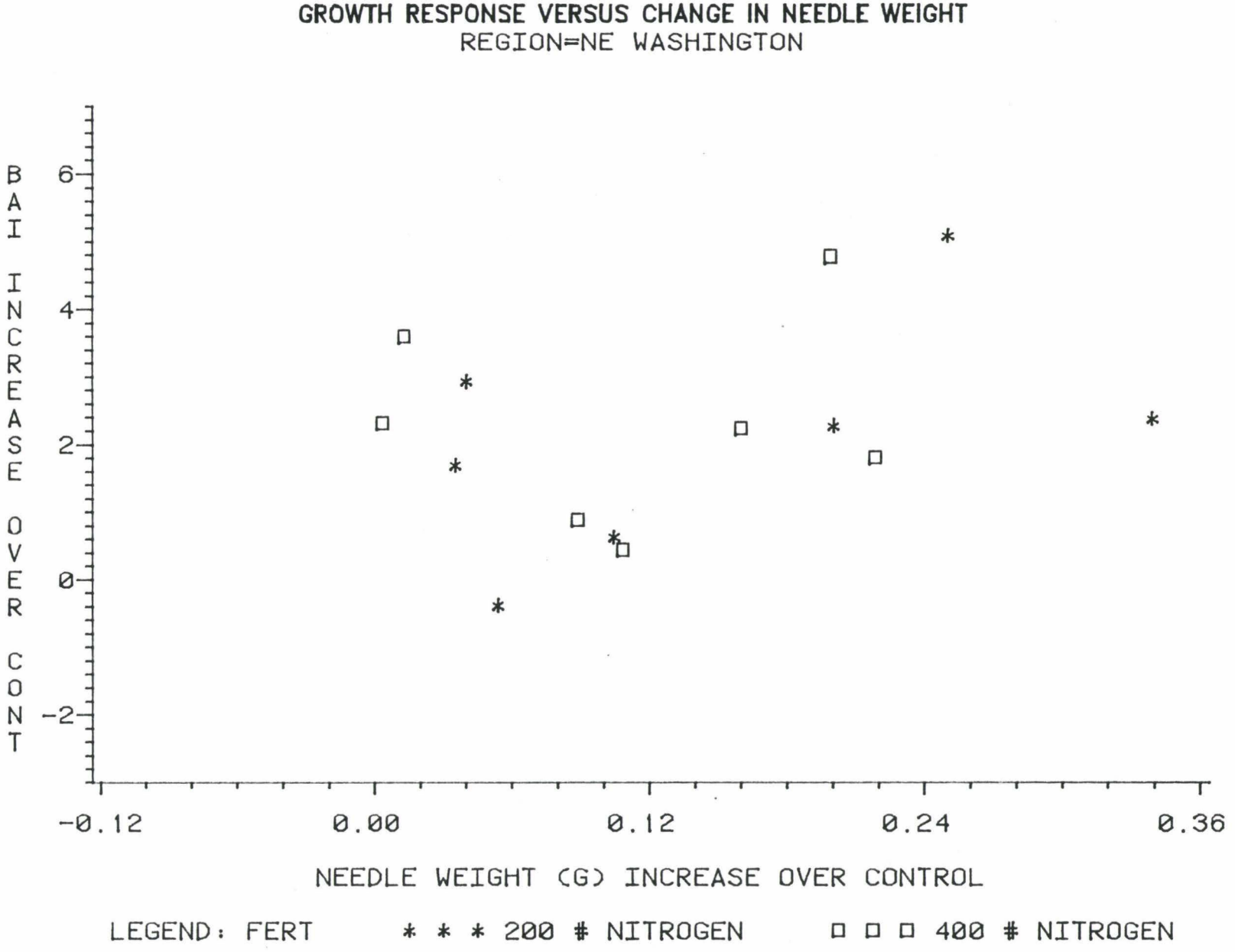

GROWTH RESPONSE VERSUS CHANGE IN NEEDLE WEIGHT
REGION=NORTH IDAHO
BAI INCREASE OVER CONT
6
4
2
0
-2
-0.12
0.00
0.12
0.24
0.36
NEEDLE WEIGHT (G) INCREASE OVER CONTROL
LEGEND: FERT * * * 200 # NITROGEN □ □ □ 400 # NITROGEN

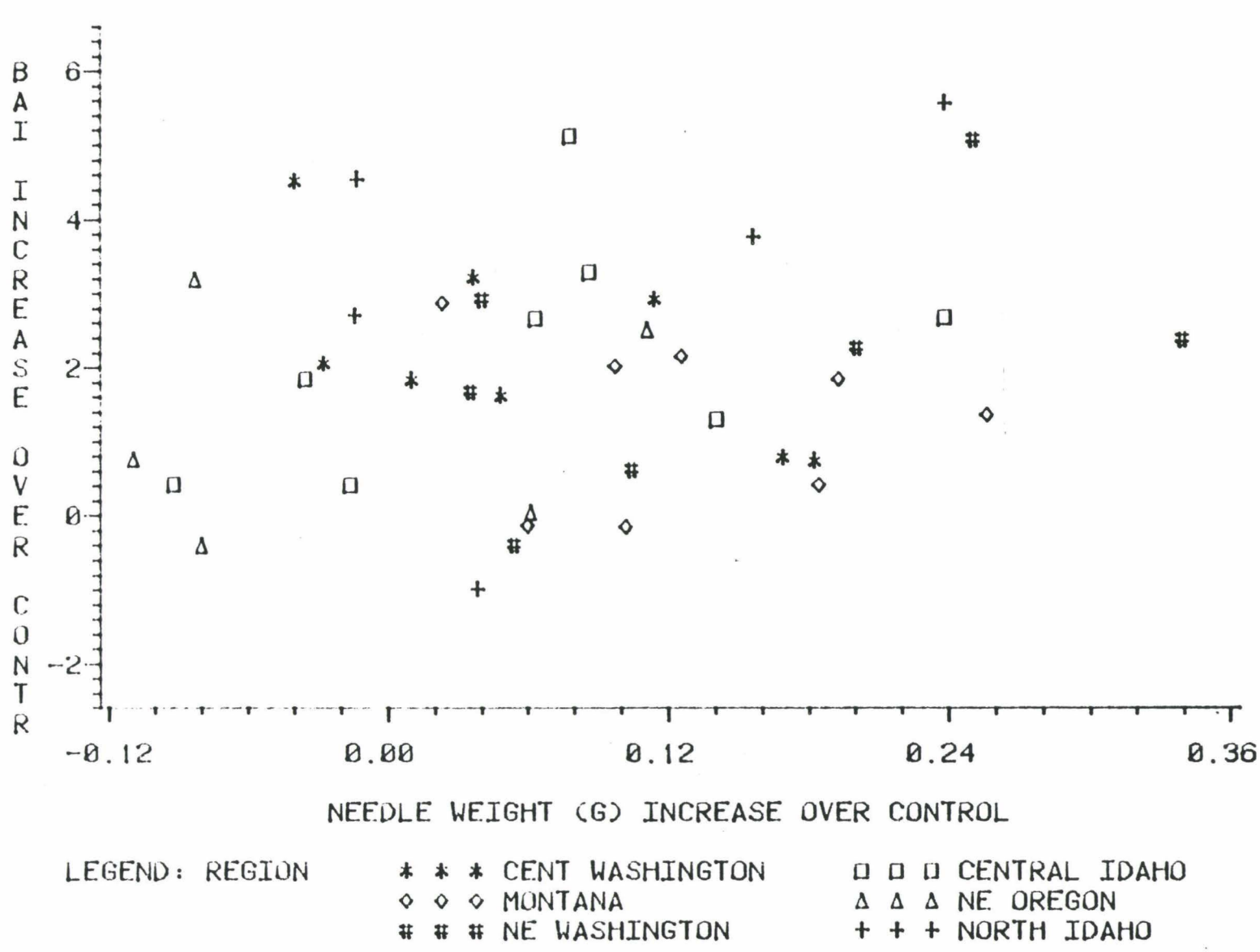

GROWTH RESPONSE VERSUS CHANGE IN NEEDLE WEIGHT
REGION=MONTANA
BAI INCREASE OVER CONT
7
6
5
4
3
2
1
0
-1
-0.1
0.0
0.1
0.2
0.3
NEEDLE WEIGHT (G) INCREASE OVER CONTROL
LEGEND: FERT * * * 200 # NITROGEN □ □ □ 400 # NITROGEN

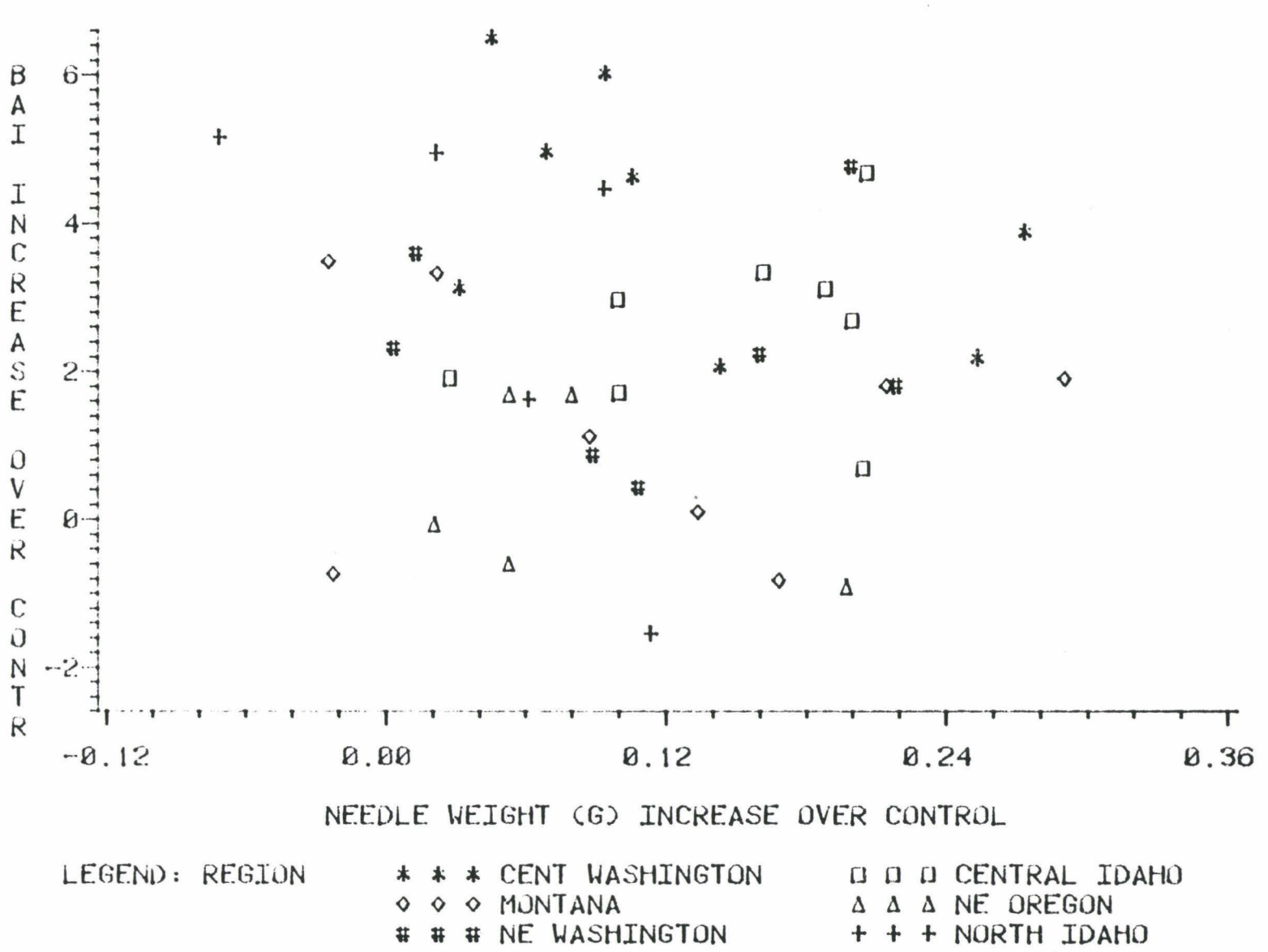

GROWTH RESPONSE VERSUS CHANGE IN NEEDLE WEIGHT
REGION=CENTRAL IDAHO
BAI INCREASE OVER CONT
7
6
5
4
3
2
1
0
-1
-0.1
0.0
0.1
0.2
0.3
NEEDLE WEIGHT (G) INCREASE OVER CONTROL
LEGEND: FERT * * * 200 # NITROGEN □ □ □ 400 # NITROGEN


GROWTH RESPONSE VERSUS CHANGE IN NEEDLE WEIGHT
REGION=NE OREGON
BAI INCREASE OVER CONT
6
4
2
0
-2
-0.12
0.00
0.12
0.24
0.36
NEEDLE WEIGHT (G) INCREASE OVER CONTROL
LEGEND: FERT * * * 200 # NITROGEN □ □ □ 400 # NITROGEN


GROWTH RESPONSE VERSUS CHANGE IN NEEDLE WEIGHT
REGION=CENT WASHINGTON
BAI INCREASE OVER CONT
7
6
5
4
3
2
1
0
-1
-0.1
0.0
0.1
0.2
0.3
NEEDLE WEIGHT (G) INCREASE OVER CONTROL
LEGEND: FERT * * * 200 # NITROGEN □ □ □ 400 # NITROGEN


GROWTH RESPONSE VERSUS CHANGE IN NEEDLE WEIGHT
REGION=NE WASHINGTON
BAI INCREASE OVER CONT
6
4
2
0
-2
-0.12
0.00
0.12
0.24
0.36
NEEDLE WEIGHT (G) INCREASE OVER CONTROL
LEGEND: FERT * * * 200 # NITROGEN □ □ □ 400 # NITROGEN


GROWTH RESPONSE VERSUS CHANGE IN NEEDLE WEIGHT
FERT=200 # NITROGEN
BAI INCREASE OVER CONTR
6
4
2
0
-2
-0.12
0.00
0.12
0.24
0.36
NEEDLE WEIGHT (G) INCREASE OVER CONTROL
LEGEND: REGION
* * * CENT WASHINGTON
◇ ◇ ◇ MONTANA
NE WASHINGTON
□ □ □ CENTRAL IDAHO
Δ Δ Δ NE OREGON
+ + + NORTH IDAHO


GROWTH RESPONSE VERSUS CHANGE IN NEEDLE WEIGHT
FERT=400 # NITROGEN
BAI INCREASE OVER CONTR
6
4
2
0
-2
-0.12
0.00
0.12
0.24
0.36
NEEDLE WEIGHT (G) INCREASE OVER CONTROL
LEGEND: REGION
* * * CENT WASHINGTON
◇ ◇ ◇ MONTANA
NE WASHINGTON
□ □ □ CENTRAL IDAHO
Δ Δ Δ NE OREGON
+ + + NORTH IDAHO

APPENDIX B

Parameter estimates (incercept) for interaction terms in the BAI regression model. Intercepts are listed on pages 4 & 5 of the Appendix.

ANALYSIS OF GROWTH RESPONSE TO NITROGEN FERTILIZATION
GROWTH MODEL WITH TREATMENT EFFECTS--1981 PLOTS
BACKWARDS ELIMINATION OF POTENTIAL INDEPENDENT VARIABLES
REGIONAL EFFECTS EXCLUDED--RUN NO. D22

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: LN_BAI LOG(BASAL AREA INCREMENT)

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	35	20.24152158	0.57832919	15.04	0.0001	0.711025	9.0735
ERROR	214	8.22656349	0.03844189		ROOT MSE		LN_BAI MEAN
CORRECTED TOTAL	249	28.46808507			0.19606602		2.16086932

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
TRT	2	3.72419343	48.44	0.0001	2	0.77126896	10.03	0.0001
PMAT	3	3.45871165	29.99	0.0001	3	0.71590115	6.21	0.0005
ASHD	3	1.21736329	10.56	0.0001	3	0.65177817	5.65	0.0011
SOILD	3	2.71048655	23.50	0.0001	3	1.53266074	13.29	0.0001
SOILN	1	0.14739746	3.83	0.0515	1	0.62074834	16.15	0.0001
SITE	1	2.77600033	72.21	0.0001	1	1.63266767	42.47	0.0001
RMSQD	1	1.10869672	28.84	0.0001	1	0.00686050	0.18	0.6731
BA81	1	0.81023772	21.08	0.0001	1	1.17949439	30.68	0.0001
SOILN*PMAT	3	0.93691058	8.12	0.0001	3	0.80407318	6.97	0.0002
RMSQD*PMAT	3	1.60190324	13.89	0.0001	3	1.42124924	12.32	0.0001
RMSQD*ASHD	3	0.43489940	3.77	0.0115	3	0.37125428	3.22	0.0234
BA81*ASHD	3	0.53739268	4.66	0.0037	3	0.45465481	3.94	0.0093
TRT*PMAT	6	0.58603217	2.54	0.0214	6	0.60320558	2.62	0.0182
BA81*TRT	2	0.19129636	2.49	0.0855	2	0.19129636	2.49	0.0855

PARAMETER		ESTIMATE	T FOR HO: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT		1.45047380 B	6.91	0.0001	0.20977578
TRT	CONTRCL	-0.21838157 B	-1.91	0.0572	0.11422324
	200 LBS NITROGEN	0.08013281 B	0.76	0.4500	0.10588739
	400 LBS NITROGEN	0.00000000 B	.	.	.
PMAT	ASH/LOESS	1.79098930 B	4.60	0.0001	0.38895297
	BASALT/SHALE	0.67922845 B	2.96	0.0034	0.22965949
	GRANITE	0.38845242 B	1.74	0.0834	0.22330894
	TILL/FILL	0.00000000 B	.	.	.
ASHD	DEEP >12"	-0.95191407 B	-1.86	0.0642	0.51164887
	MODERATE 3-12"	-0.76538694 B	-1.86	0.0640	0.41110600
	SHALLOW <3"	-1.36476423 B	-3.92	0.0001	0.34797216
	ZERO	0.00000000 B	.	.	.
SOILD	DEEP >24"	0.23819179 B	3.04	0.0027	0.07837512
	MODERATE 12-24"	0.00947923 B	0.12	0.9039	0.07843752
	SHALLOW <12"	0.04234250 B	0.52	0.6062	0.08201776
	VARIABLE	0.00000000 B	.	.	.
SOILN		-0.00013399 B	-5.37	0.0001	0.00002494
SITE		0.00820387	6.52	0.0001	0.00125885
RMSQD		0.04179352 B	2.50	0.0130	0.01668459
BA81		0.00093125 B	1.33	0.1833	0.00069763

ANALYSIS OF GROWTH RESPONSE TO NITROGEN FERTILIZATION
GROWTH MODEL WITH TREATMENT EFFECTS--1981 PLOTS
BACKWARDS ELIMINATION OF POTENTIAL INDEPENDENT VARIABLES
REGIONAL EFFECTS EXCLUDED--RUN NO. D22

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: LN_BAI LOG(BASAL AREA INCREMENT)

PARAMETER			ESTIMATE	T FOR HO: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
SOILN*PMAT	ASH/LOESS		0.00014729 B	4.06	0.0001	0.00003627
	BASALT/SHALE		0.00010857 B	3.36	0.0009	0.00003234
	GRANITE		-1.4837823E-05 B	-0.26	0.7931	0.00005650
	TILL/FILL		0.00000000 B	.	.	.
RMSQD*PMAT	ASH/LOESS		-0.19069743 B	-5.89	0.0001	0.032402C1
	BASALT/SHALE		-0.08422219 B	-4.53	0.0001	0.01858399
	GRANITE		-0.06759992 B	-2.98	0.0032	0.02264869
	TILL/FILL		0.00000000 B	.	.	.
RMSQD*ASHD	DEEP >12"		0.01845275 B	0.37	0.7112	0.04976471
	MODERATE 3-12"		0.05253062 B	1.35	0.1788	0.03894598
	SHALLOW <3"		0.07330764 B	2.75	0.0066	0.02669855
	ZERO		0.00000000 B	.	.	.
BA81*ASHD	DEEP >12"		0.00466595 B	2.75	0.0064	0.00169546
	MODERATE 3-12"		0.00031851 B	0.24	0.8129	0.00134403
	SHALLOW <3"		0.00286731 B	2.41	0.0168	0.00118946
	ZERO		0.00000000 B	.	.	.
TRT*PMAT	CONTROL	ASH/LOESS	-0.28269584 B	-3.29	0.0012	0.08596935
	CONTROL	BASALT/SHALE	-0.29635999 B	-3.43	0.0007	0.08644232
	CONTROL	GRANITE	-0.25854403 B	-2.33	0.0208	0.11100313
	CONTROL	TILL/FILL	0.00000000 B	.	.	.
	200 LBS NITROGEN	ASH/LOESS	-0.15110945 B	-1.80	0.0740	0.08415375
	200 LBS NITROGEN	BASALT/SHALE	-0.09038031 B	-1.05	0.2952	0.08612380
	200 LBS NITROGEN	GRANITE	-0.16397211 B	-1.45	0.1489	0.11319963
	200 LBS NITROGEN	TILL/FILL	0.00000000 B	.	.	.
	400 LBS NITROGEN	ASH/LOESS	0.00000000 B	.	.	.
	400 LBS NITROGEN	BASALT/SHALE	0.00000000 B	.	.	.
	400 LBS NITROGEN	GRANITE	0.00000000 B	.	.	.
	400 LBS NITROGEN	TILL/FILL	0.00000000 B	.	.	.
BA81*TRT	CONTROL		0.00134665 B	1.77	0.0776	0.00075947
	200 LBS NITROGEN		-0.00032767 B	-0.46	0.6424	0.00070474
	400 LBS NITROGEN		0.00000000 B	.	.	.

NOTE: THE X'X MATRIX HAS BEEN DEEMED SINGULAR AND A GENERALIZED INVERSE HAS BEEN EMPLOYED TO SOLVE THE NORMAL EQUATIONS. THE ABOVE ESTIMATES REPRESENT ONLY ONE OF MANY POSSIBLE SOLUTIONS TO THE NORMAL EQUATIONS. ESTIMATES FOLLOWED BY THE LETTER B ARE BIASED AND DO NOT ESTIMATE THE PARAMETER BUT ARE BLUE FOR SOME LINEAR COMBINATION OF PARAMETERS (OR ARE ZERO). THE EXPECTED VALUE OF THE BIASED ESTIMATORS MAY BE OBTAINED FROM THE GENERAL FORM OF ESTIMABLE FUNCTIONS. FOR THE BIASED ESTIMATORS, THE STD ERR IS THAT OF THE BIASED ESTIMATOR AND THE T VALUE TESTS HO: E(BIASED ESTIMATOR) = 0. ESTIMATES NOT FOLLOWED BY THE LETTER B ARE BLUE FOR THE PARAMETER.

PARAMETER	ESTIMATE	T FOR HO: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
SN--ASH/LOESS	1.3292252E-05	0.52	0.6037	0.00002557
SN--BASALT	-2.5426462E-05	-1.15	0.2517	0.00002212
SN--GRANITE	-0.00014883	-2.77	0.0061	0.00005374
SN--TILL/FILL	-0.00013359	-5.37	0.0001	0.00002494

INTERMOUNTAIN FOREST TREE NUTRITION COOPERATIVE
ANALYSIS OF GROWTH RESPONSE TO NITROGEN FERTILIZATION
GROWTH MODEL WITH TREATMENT EFFECTS--1981 PLOTS
BACKWARDS ELIMINATION OF POTENTIAL INDEPENDENT VARIABLES
REGIONAL EFFECTS EXCLUDED--RUN NO. D22

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: LN_BAI LOG(BASAL AREA INCREMENT)

PARAMETER	ESTIMATE	T FOR HO: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
BA--D ASH--CONTROL	0.00694384	4.18	0.0001	0.00165998
BA--D ASH--200 LBS	0.00526953	3.16	0.0018	0.00166809
BA--D ASH--400 LBS	0.00559720	3.45	0.0007	0.00162029
BA--M ASH--CONTROL	0.00259640	1.98	0.0492	0.00131269
BA--M ASH--200 LBS	0.00092209	0.71	0.4782	0.00129781
BA--M ASH--400 LBS	0.00124975	0.99	0.3241	0.00126458
BA--S ASH--CONTROL	0.00514520	4.41	0.0001	0.00116680
BA--S ASH--200 LBS	0.00347089	3.09	0.0022	0.00112194
BA--S ASH--400 LBS	0.00379856	3.39	0.0008	0.00111950
BA--NO ASH--CONTROL	0.00227789	2.88	0.0044	0.00079141
BA--NO ASH--200 LBS	0.00060358	0.87	0.3862	0.00069508
BA--NO ASH--400 LBS	0.00093125	1.33	0.1833	0.00069763
RMSQD--D ASH/LOESS	-0.13045116	-3.25	0.0013	0.04013328
RMSQD--M ASH/LOESS	-0.09637328	-3.80	0.0002	0.02535817
RMSQD--S ASH/LOESS	-0.07559627	-6.58	0.0001	0.01148716
RMSQD--S ASH/BASALT	0.03087897	1.32	0.1886	0.02341405
RMSQD--NO ASH/BASALT	-0.04242867	-3.09	0.0022	0.01371033
RMSQD--GRANITE	-0.02580640	-1.41	0.1611	0.01834992
RMSQD--TILL/FILL	0.04179352	2.50	0.0130	0.01668459
I--D A/L, D SOIL, CO	2.02666341	5.30	0.0001	0.38209510
I--M A/L, D SOIL, CO	2.21319054	8.59	0.0001	0.25771195
I--M A/L, M SOIL, CO	1.98447797	7.70	0.0001	0.25762497
I--S A/L, D SOIL, CO	1.61381324	7.40	0.0001	0.21822826
I--S A/L, M SOIL, CO	~~1.98447797~~ 1.38570062	~~7.70~~	0.0001	~~0.25762497~~
I--S A/L, S SOIL, CO	1.41796396	6.49	0.0001	0.21856507
I--S A/L, V SOIL, CO	1.37562145	5.93	0.0001	0.23206460
I--S A/B, D SOIL, CO	0.48838824	1.43	0.1541	0.34145122
I--S A/B, M SOIL, CO	0.25967568	0.76	0.4452	0.33950364
I--S A/B, S SOIL, CO	0.29253896	0.86	0.3932	0.34195623
I--NO A/B, D SOIL, C	1.85315248	11.51	0.0001	0.16097860
I--NO A/B, M SOIL, C	1.62443991	10.05	0.0001	0.16157334
I--NO A/B, S SOIL, C	1.65730319	10.24	0.0001	0.16187714
I--GRANITE, D SOIL,	1.60019241	9.14	0.0001	0.17513200
I--GRANITE, M SOIL,	1.37147985	7.99	0.0001	0.17157041
I--T/F, D SOIL, CONT	1.47028402	7.13	0.0001	0.20628361
I--T/F, M SOIL, CONT	1.24157145	6.14	0.0001	0.20210364
I--T/F, S SOIL, CONT	1.27443473	6.40	0.0001	0.19906334
I--D A/L, D SOIL, 20	2.45676418	6.21	0.0001	0.39545465
I--M A/L, D SOIL, 20	2.64329131	10.71	0.0001	0.24675277
I--M A/L, M SOIL, 20	2.41457875	9.72	0.0001	0.24829289
I--S A/L, D SOIL, 20	2.04391402	9.68	0.0001	0.21113939
I--S A/L, M SOIL, 20	~~2.41457875~~ 1.81520146	~~9.72~~	0.0001	~~0.24829289~~
I--S A/L, S SOIL, 20	1.84806473	8.68	0.0001	0.21293173
I--S A/B, D SOIL, 20	0.99288230	2.88	0.0044	0.34523481
I--S A/B, M SOIL, 20	0.76416974	2.22	0.0273	0.34373868
I--NO A/B, D SOIL, 2	2.35764654	14.89	0.0001	0.15838362
I--NO A/B, M SOIL, 2	2.12893398	13.31	0.0001	0.15991444

Intercepts No fertilizer

Intercepts 200 # N/ac

INTERMOUNTAIN FOREST TREE NUTRITION COOPERATIVE 11:10 THURSDAY, NOVEMBER 29, 1984
ANALYSIS OF GROWTH RESPONSE TO NITROGEN FERTILIZATION
GROWTH MODEL WITH TREATMENT EFFECTS--1981 PLOTS
BACKWARDS ELIMINATION OF POTENTIAL INDEPENDENT VARIABLES
REGIONAL EFFECTS EXCLUDED--RUN NO. D22

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: LN_BAI LOG(BASAL AREA INCREMENT)

PARAMETER	ESTIMATE	T FOR HO: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
I--NO A/B, S SOIL, 2	2.16179725	13.55	0.0001	0.15955642
I--NO A/B, V SOIL, 2	2.11945475	12.78	0.0001	0.16579129
I--GRANITE, D SOIL,	1.99327872	11.22	0.0001	0.17760309
I--GRANITE, M SOIL,	1.76456615	10.10	0.0001	0.17465804
I--GRANITE, V SOIL,	1.75508693	10.01	0.0001	0.17537112
I--T/F, M SOIL, 200L	1.54008583	7.92	0.0001	0.19455815
I--T/F, S SOIL, 200L	1.57294911	8.24	0.0001	0.19096246
I--T/F, V SOIL, 200L	1.53060661	7.47	0.0001	0.20502177
I--D A/L, D SOIL, 40	2.52774083	6.58	0.0001	0.38386763
I--M A/L, D SOIL, 40	2.71426795	10.82	0.0001	0.25085616
I--M A/L, M SOIL, 40	2.48555539	9.87	0.0001	0.25177989
I--M A/L, V SOIL, 40	2.47607616	9.19	0.0001	0.26952725
I--S A/L, D SOIL, 40	2.11489066	9.97	0.0001	0.21218531
I--S A/L, M SOIL, 40 Intercepts 400 #N/ac	~~2.48555539~~ 1.88617810	~~9.87~~	0.0001	~~0.25177989~~
I--S A/L, S SOIL, 40	1.91904137	9.05	0.0001	0.21209136
I--S A/B, M SOIL, 40	0.77441724	2.26	0.0248	0.34262569
I--S A/B, S SOIL, 40	0.80728052	2.35	0.0198	0.34375640
I--S A/B, V SOIL, 40	0.76493801	2.17	0.0314	0.35308237
I--NO A/B, D SOIL, 4	2.36789403	15.39	0.0001	0.15386996
I--NO A/B, M SOIL, 4	2.13918147	13.76	0.0001	0.15548167
I--NO A/B, S SOIL, 4	2.17204475	14.21	0.0001	0.15289728
I--GRANITE, D SOIL,	2.07711801	12.44	0.0001	0.16695603
I--GRANITE, M SOIL,	1.84840545	11.21	0.0001	0.16494947
I--T/F, M SOIL, 400L	1.45995303	7.46	0.0001	0.19567552
I--T/F, S SOIL, 400L	1.49281630	7.83	0.0001	0.19053430
I--T/F, V SOIL, 400L	1.45047380	6.91	0.0001	0.20977578